INSTITUTO
UNIVERSITÁRIO
DE LISBOA

Housing Co-design: A Graphic User Interface to support customisation

Micaela Martins Raposo

Doctorate Degree (PhD) in Architecture of Contemporary Metropolitan Territories

Supervisors:
Ph.D. Sara Eloy, Associate Professor,
University of Antwerp

Ph.D. Miguel Sales Dias, Full Professor
Iscte- Instituto Universitário de Lisboa

December, 2025

TECNOLOGIAS
E ARQUITETURA

Department of Architecture and Urbanism

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Jury:

Ph.D. Bernardo João Pizarro de Campos Miranda, Assistant Professor, Iscte – Instituto Universitário de Lisboa (President)

Ph.D. José Manuel Pinto Duarte, Full Professor, Penn State University (USA)

Ph.D. Deborah Helena do Rosario Benrós, Senior Lecturer, University of East London (England)

Ph.D. Paula Alexandra Gomes da Silva, Assistant Professor, University of Coimbra

Ph.D. Maria Teresa Marques Madeira da Silva, Associate Professor with Habilitation, Iscte – Instituto Universitário de Lisboa

Ph.D. Sara Eloy Cardoso Rodrigues, Associate Professor, University of Antwerp (Belgium)

December, 2025

“Providing housing is just a start, providing one that fits the individual needs of families is one of the next challenges.”

Tian Tian Lo, Marc Aurel Schnabel, and Serdar Aydin

Acknowledgements

Reaching the end of an intense journey of highs and lows that gave shape to this thesis, I would like to thank everyone who directly or indirectly accompanied me throughout this journey.

First and foremost, I wish to express my deepest gratitude to my boyfriend, Fábio Costa, for his unwavering support in every respect. His patience, encouragement, and emotional strength became a source of resilience I never knew I possessed. In moments of doubt, his kindness restored my confidence and gave me courage. His constant presence has been a safe haven, and words will never be sufficient to convey the importance he has, and will always have, in my life.

I am also profoundly grateful to my supervisors, Professor Sara Eloy and Professor Miguel Sales Dias, for their enthusiasm, rigour, and dedication to this research. I am grateful to them for the trust they placed in me, for their tireless guidance, and for the invaluable knowledge they shared. Their contributions were indispensable for this thesis's robustness, and I am convinced that I could not have wished for a better supervisory team. Beyond the academic work, these years have been enriched by shared experiences and the forging of bonds that transcend the professional sphere. I conclude this stage with two friends I will carry with me for life.

I extend my sincere thanks to all participants in the various stages of the iterative study: the professionals in architecture, urban planning, and social sciences; the representatives and residents of housing cooperatives; and the participants in user testing, including end-users, interface experts and architects. I am truly grateful to each of you for generously giving your time and providing valuable insights, without which this research would not have been possible.

To my friends, and especially to the group of doctoral colleagues with whom my supervisor integrated me, I am thankful for the conversations, the valuable exchange of experiences, and the company that turned us into lifelong friends.

I cannot fail to acknowledge my family for their unconditional support. In both good and difficult times, they were always present, whether physically or remotely, cheering me on. To my parents, who are part of me and to whom I owe all that I am. To my dear sisters, with whom I have always walked hand in hand. To my beloved cousin and my uncles, my brothers-in-law and my parents-in-law, whose daily support made this journey far less arduous. A special word of thanks goes to my niece, Sofia Silva, who so often listened to me and offered her opinions on diagrams and presentations throughout these years.

Finally, I wish to leave a very special acknowledgement to Buster, to whom I dedicate this thesis. More than a dog, he was part of our family, my third brother, and a truly significant presence in our lives. During the course of this research, he left us, yet he remains ever-present in our hearts. For us, he is a symbol of resilience and strength, and he will never be forgotten 🐾

Institutional acknowledgments

This work was supported by National Funds through Fundação para a Ciência e a Tecnologia, I.P. (FCT), through the grant SFRH/BD/146044/2019, and under the ISTAR projects: UIDB/04466/2020 and UIDP/04466/2020.

Resumo

A oferta de habitação nas cidades contemporâneas é dominada por modelos padronizados, produzidos em massa e impessoais, que não respondem às necessidades individuais das suas populações. Apesar das experiências levadas a cabo em projeto participativo, com o objetivo de aumentar a personalização, a colaboração ativa dos utilizadores finais no desenho de soluções permanece limitada, sobretudo na habitação coletiva. As tecnologias digitais podem colmatar esta lacuna ao recorrerem à automatização de sistemas de desenho gerativo capazes de produzir e validar rapidamente soluções que respondam à diversidade dos utilizadores. Adicionalmente, estas ferramentas proporcionam modos eficazes de representação que facilitam a compreensão do espaço. Porém, faltam ferramentas que permitam aos habitantes expressar necessidades e traduzi-las em propostas de projeto.

Esta tese aborda este desafio propondo a personalização da habitação através de uma interface gráfica de utilizador integrada em processos de co-design, com foco particular em cooperativas de habitação e em modelos de habitação acessível. Os objetivos são definir os requisitos que uma ferramenta digital deve cumprir para promover o envolvimento dos utilizadores finais, desenvolver uma interface centrada na experiência do utilizador, e avaliar o seu impacto no co-design de habitação.

Seguindo uma metodologia de desenho centrado no utilizador, entrevistas informaram o desenvolvimento iterativo da interface, testada com potenciais utilizadores, especialistas em usabilidade e arquitetos, obtendo resultados positivos.

Os resultados demonstram que as tecnologias digitais podem apoiar eficazmente a colaboração entre arquitetos e habitantes, permitindo uma participação informada e aumentando a satisfação com o processo e os resultados. A investigação confirma que uma colaboração efetiva requer o envolvimento direto dos utilizadores finais, garantindo que as ferramentas de desenho incorporem os seus contributos e se alinhem com as suas necessidades e preferências.

Palavras-chave: Habitação personalizada, Co-design, Tecnologias digitais, Interface Gráfica de Utilizador (GUI), Desenho Centrado no Utilizador.

Abstract

Housing provision in contemporary cities is dominated by standardised, mass-produced, and impersonal models that fail to address the individual needs of their populations. While participatory approaches have sought to enhance customisation, genuine collaborative processes in which end-users actively contribute to the formulation of solutions remain limited, particularly in collective and mass housing. Digital technologies offer significant potential to address this gap by resorting to the automation of generative design systems capable of rapidly producing and validating solutions responsive to user diversity. Additionally, these tools provide effective modes of representation that facilitate the understanding of space. However, tools that enable inhabitants to articulate their needs and translate them into design proposals are still lacking.

This thesis addresses this challenge by proposing housing customisation through a graphical user interface integrated into co-design processes, with a particular focus on cooperative housing and affordable housing models. The research goals are to define the requirements such a tool must meet to foster meaningful end-user engagement, develop a user-centred interface focused on the user experience, and evaluate its impact on housing co-design.

Following a user-centred design methodology, interviews informed the interface's subsequent iterative development. The interface was tested with potential users, usability experts, and architects, obtaining positive feedback.

Findings demonstrate that digital technologies can effectively support collaboration between architects and inhabitants, enabling informed participation and increasing satisfaction with both process and outcomes. The research confirms that effective collaboration requires direct engagement with end-users, ensuring that design tools incorporate their input and align with their needs and preferences.

Keywords: Housing customisation, Co-design, Digital technologies, Graphical User Interface (GUI), User-centred design.

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Glossary of Acronyms

BIM: Building Information Modelling

CAD: Computer-Aided Design

CAM: Computer-Aided Manufacturing

DSRM: Design Science Research Methodology

GUI: Graphical User Interface

HCI: Human-Computer Interaction

HMD: Head Mounted Display

PD: Participatory Design

PP: Participatory Processes

SEQ: Single Ease Question

SUS: System Usability Scale

UCD: User-Centred Design

UX: User experience

UI: User Interface

CHAPTER 1: Introduction

The need for customisation is becoming increasingly important in different fields as individuals seek products and services that meet their unique needs and preferences. In architecture, the end-users' satisfaction regarding the built environment depends largely on how the space suits their needs. This is especially true when it comes to designing houses. Housing is an essential good, and its customisation greatly impacts people's quality of life (Yavari et al., 2015). However, accommodating all end users' specific wishes and requirements is challenging in architectural design. As stated by Lo, Schnabel and Aydin "Providing housing is just a start, providing one that fits the individual needs of families is one of the next challenges." (Lo et al., 2016, p. 339).

In collective and mass housing contexts, residents often feel unsatisfied because they do not identify with their housing design. This situation is more frequent in housing designed for the middle and lower classes, as in social housing cases (Noguchi & Hernàndez-Velasco, 2005). In these cases, houses are usually designed for unknown clients and following standards, which means that they are designed mainly according to what the designer considers necessary (Van Der Linden et al., 2018). However, the solution of houses designed with the same spatial characteristics does not address the diversity of individual inhabitants' needs. By excluding the future inhabitants from the design process, the houses cause dissatisfaction (Önder et al., 2010), and inhabitants feel the need to make changes as soon as they move in or may even leave the house (Davidson et al., 2007). Therefore, to truly achieve customised housing, end users must participate in the design process from the initial stages, during which crucial decisions are made. The participation of the end users in the design process is a crucial aspect for achieving a successful design. Enabling inhabitants to have control over their future houses addresses housing customisation and democratises architecture by letting society have a voice and play an active role in the development of the housing industry.

Participatory design (PD) allows for a customised and user-centric approach to housing design. It ensures that the dwellings meet the users' needs and preferences, leading to more satisfied homeowners and a better quality of living (Önder et al., 2010). Such an approach to architectural design concerns the active involvement of end-users in the design process, allowing them to contribute their ideas and feedback to create solutions that meet their needs. PD addresses both social and functional issues by, on the one hand, increasing identity and customisation and, on the other hand, incorporating the expertise of the designer. Several benefits of PD are identified in the literature, including increasing user satisfaction, a sense of belonging, and community empowerment (Marschall, 1998; Sanoff, 2008).

Participatory design has been particularly successful in affordable housing projects, where community involvement has been shown to lead to better design outcomes and greater user satisfaction across the world in countries such as Colombia (Davidson et al., 2007), Turkey (Önder et al., 2010), and Palestine (Ammar et al., 2013). However, as Davidson et al. (2007) found, some participation levels are ineffective for user satisfaction because of their lack of active involvement by the inhabitants in the design definition. According to Sherry Arnstein, different levels of participation can be applied in the design process, from the mere information and consultation of the user's needs to a more active role of the community in the decision-making process (Arnstein, 1969). According to Combrinck and Porter (2021), co-design is an approach in which the stakeholders collaborate in the decision-making process with the same authority level and contribute actively to the design proposal. Brandt, Binder, and Sanders (2013) state that "making activities" during the design process helps non-experts in architecture to express their ideas.

Participatory processes and co-design initiatives through face-to-face participation methods, such as meetings and workshops, allow end users to take an active role while the architect acts as moderator. Society has been participating in design processes in public spaces, housing, and educational facilities. The Patio, for example, was a top-down initiative by the public administration in Hammarkullen, Sweden, which aimed to carry out a series of workshops in which citizens collaborated in the planning and construction of a stage in the public space (Stenberg, 2013). In the Netherlands, Álvaro Siza Vieira designed the Punt en Komma housing complex in a participatory process as part of the urban renewal of the Schilderswijk district of the Hague city, where inhabitants have experienced full-scale models to help them determine their requirements (Mota, 2019). La Mémé, a medical students' residence of the Université Catholique de Louvain (UCL), designed by Lucien Kroll in Brussels, is another example of a participatory process, where hands-on workshops were carried out between the architect and his team, UCL officials and the medical students to create a design to unify the campus (Patel, 2016).

However, participatory processes carry some difficulties as the end-users lack understanding, skills and experience in architecture (Marschall, 1998). Besides the lack of technical knowledge, there is also a lack of tools that help them effectively communicate and give form to their wishes. This situation makes it difficult to find common ground between designers and the end users of the built environment, leading to a communication gap.

In recent years, digital technologies have been extensively used to support humans in tasks that require knowledge they do not have and as interfaces between experts and laymen. Digital technologies can address this issue as they can transform how people engage with the design. They have the potential to significantly impact participatory processes in architecture by improving the end-users' understanding of the space and design possibilities. The ability to show the consequences of the

user's actions on the design in real time is an example of how digital technologies empower end-user involvement. Several studies have shown that the use of realistic representations of architecture, such as image rendering of 3D models, improves the understanding of space by non-specialists in architecture (Al-Kodmany, 2001; Salter et al., 2009; Schroth et al., 2006). Additionally, digital technologies also play a significant role in enabling the design of mass customisation. Generative design is a computational process in which the computer generates multiple design solutions based on parameters. This process allows for the exploration of multiple design options in a short amount of time (Tomić et al., 2023). Using generative design systems, such as parametric design and shape grammars, can respond to the problem of housing customisation, as they enable the creation of a wide range of design solutions that respond to the diversity of inhabitants' needs while complying with construction regulations. By using such design systems, the user can adjust the parameters to accommodate their specific needs and generate design solutions that fit them. Using such a system for co-design should not require technical knowledge from the end user.

To tackle house customisation, this research proposes the use of a digital design tool based on generative design during co-design processes. The PhD research focuses on the development and testing of a graphical user interface of such a tool to be used by end-users, i.e. future inhabitants, when co-designing their houses. The development of interactive systems requires an iterative, user-centred methodology that enables a thorough understanding of both the user and the problem, thereby supporting the design of the user experience before implementation (Gonçalves et al., 2017). The definition of the system architecture and the software development and technical implementation (e.g., based on generative systems) fall outside the scope of the iterative model.

This thesis does not develop the design rules that inform the generative system. Instead, it focuses on the design of the user interface, specifically by investigating the user experience, which has been identified as a gap in the literature. The user interface and the generative design systems are conceived as distinct yet interrelated components: the interface structures how users access, interpret, and act upon them while the generative systems encode the design rules and disciplinary knowledge. That said, the interface is envisioned as a mediator that connects users to potential multiple generative design languages without requiring direct engagement with their underlying technical complexity. It should enable inhabitants to make informed decisions through the implicit integration of design rules embedded by architects within these systems. Such rules are defined by expert designers at the outset and include compliance with building code legislation as well as the coordination of various technical domains, including structural and mechanical systems such as ventilation, plumbing, and electricity. In this way, the generative systems organise and enforce the constraints inherent to architectural design, while the interface translates them into accessible forms of guidance, thereby constraining and informing inhabitants' choices.

Such a co-design tool can be used in contexts where the end-users are known before the construction so that they can be actively involved in the design definition of their houses. The use of this tool is viable in contexts such as (1) the third sector, i.e., in housing cooperatives, where a group of people come together on an organisation to construct their houses: (2) public initiatives, e.g., when municipal authorities relocate specific communities for better housing conditions, and thus the end-users are known and can be part of the design process; and (3) the private sector when an individual client looks for an architect to design a tailored house: the tool can be used for the household to make their own decisions about the house.

Collective housing contexts, such as the public initiatives and housing cooperatives mentioned above, can refer to apartment buildings and housing complexes consisting of individual houses. The focus of this research is housing cooperatives, exemplified through a case study of apartment buildings.

1.1 Research problem

Over the last 40 years, work has been done to develop computational design tools to answer the need to create design alternatives that match the needs of end users. Such work aimed to create design tools that assist in identifying the inhabitants' wishes and needs and define a housing design that responds to them.

Some research prototypes based on generative design systems were developed to generate solutions that respond to user inputs introduced during the first steps of the system use. Examples are MALAG (Duarte & Correia, 2006), Barcode Housing System (Madrazo et al., 2010), i_Prefab Home (Huang & Krawczyk, 2007), and ABC-based Customized Mass-Housing Generator (Benrós & Duarte, 2009). These systems provide a set of parameters that can be adjusted to match the user's preferences. Another group of prototypes helps the user to create the house layout, on a step-by-step basis, according to the decisions made during the design process. Examples of such generative design tools are HouseMaker (MVRDV & Axis.fm, 2012), Group Forming (Ong et al., 2013), and ModRule (Lo et al., 2015).

Additionally, implemented commercial solutions such as IKEA Home and Kitchen Planner (Inter IKEA Systems B.V., 1999), Sweet Home 3D (ETeks, 2006), and Room Sketcher (RoomSketcherAS, 2007) were developed. Such systems are available online to allow inhabitants to customise their living spaces (including the layout, finishings, and furniture), designing them from scratch according to their preferences instead of initially introducing their requirements, such as the previously mentioned systems. Some of these tools do not incorporate knowledge from construction regulations and can mislead users about their designs' functionality and construction viability.

The tools mentioned are important contributions to customising housing projects. While some are based on generative design, others incorporate tools for designing from scratch. However, the existing tools for customising housing are not intended for a non-technical audience (i.e., the tools are designed to be used by architects) or, when they are, the tools do not restrict the possibilities to good architectural practices and regulations. While digital technologies have brought significant benefits to customisation and participatory processes that can address these gaps, developing user-friendly interfaces is crucial so inhabitants can easily interact with the housing design. User-centred design aims to develop the right products for a concrete user problem, that are easy to use and that delight the end-user. Actively involving users in the design process and evaluating them iteratively leads to products that meet their requirements and facilitate their satisfaction (Gonçalves et al., 2017).

The research problem identified is the **lack of user involvement in designing graphical user interfaces of housing co-design tools**. Although effective customisation and participation require tools that combine the potential of generative design with user-friendly interfaces, no evidence was found in the literature of end-user involvement in the design of such tools. It is necessary to involve end users iteratively in various design development stages rather than just testing a final product. Therefore, there is a need to develop user-friendly, natural, and accessible interfaces that focus on the user experience to respond to users' needs, to effectively support end-users in co-designing customised houses.

1.2 Research questions, hypotheses and goals

Research Questions

This work raises three research questions:

(RQ1) Which requirements should a digital housing design tool meet to effectively support end-user collaboration?

(RQ2) How effectively can digital housing co-design tools enable inhabitants to interact with architectural design in an informed manner to realise customised housing?

(RQ3) What are the benefits and limitations of inhabitants using a digital design tool in the scope of a co-design process and definition of customised housing?

Hypotheses

Two hypotheses were formulated to respond to the research questions:

(H1) The requirements for enabling effective end-user collaboration through a housing digital tool can be collected by using a user-centred design methodology: The gathering of information from

direct contact and empathy with potential end-users allows for defining user requirements aligned with their needs.

(H2) Digital tools enhance collaboration between inhabitants and architects in housing projects by enabling residents to actively participate in design decisions: Using digital technologies improves end-user understanding. Therefore, they have the potential to enhance inhabitants' collaboration in the design process through a natural and simple interface that allows them to easily interact with the design of their houses.

(H3) The use of digital tools in the co-design of housing, by enabling housing customisation, contributes to end users' satisfaction in both the design process and the resulting house designs: Digital tools can enhance end-user satisfaction with the design process by facilitating collaboration *between architects and inhabitants*. By enabling housing customisation, these tools contribute to satisfaction with the final outcomes of the house designs.

Goals

The main goal of this research is to define a framework composed of a design process and a Graphical User Interface (GUI) to address the customisation of houses in a co-design process, focusing on the user experience. Three specific goals were defined to answer the research questions and verify the formulated hypothesis:

(G1) Define the requirements that enable inhabitants to co-design their houses:

Collect, analyse and define the requirements relevant to developing a GUI that aids the co-design of customised housing. These requirements are related to the necessary conditions for the inhabitants to actively collaborate in the design process and four main aspects of the interface: (1) architectural design elements that users interact with (e.g. house functions, size of rooms, shape of rooms, walls, doors, materials), (2) the type of visualisation (e.g. floor plans, image rendering perspectives, interactive 3D), (3) the type of interaction (drag and drop, sliders, forms filling) and the (4) type of interface virtual or material (e.g. computer screen, HMD, digital table, tablet, smartphone).

(G2) Define and test an interface solution for the co-design of housing focusing on the user experience:

Define a framework with a design process and an interface that inhabitants can use to collaborate with an architect when designing their houses. The framework aims simultaneously to incorporate architects' technical knowledge and empower inhabitants to participate in a democratised architectural design. Proposing an interface for a system based on generative design aims to enhance architects' support when collaborating with clients, enabling a creative, asynchronous interaction between inhabitants and architects. Besides defining the framework, the aim is to focus on the

development of the GUI for inhabitants, testing the solution, and measuring usability and user satisfaction.

(G3) Gather the perspectives of architects and inhabitants on collaborative house design, particularly in relation to utilising the proposed graphical user interface:

By collecting the perspectives of architects and inhabitants, this research aims to evaluate the impact of using such an interface for co-designing customised housing. Both perspectives will be collected before and after using the proposed interface to identify its benefits and limitations. Inhabitants' satisfaction will be evaluated as well, and architects' perspectives will be collected from the point of view of an expert in architecture.

Table 1 relates the research questions, hypotheses, and goals. Achieving the first goal (G1) allows to address the first research question (RQ1) and verify the first hypothesis. The results of the second goal (G2) will enable to address the second research question (RQ2) and verify the second hypothesis (H1). Finally, the third goal (G3) addresses the third research question (RQ3) and verifies the third hypothesis (H2).

Table 1_Relationship between research questions, hypotheses and goals.

Research question	Hypothesis	Goal
RQ1- Which requirements should a digital housing design tool meet to effectively support end-user collaboration?	**H1**- The requirements for enabling effective end-user collaboration through a housing digital tool can be collected by using a user-centred design methodology.	**G1-** Define the requirements that enable inhabitants to co-design their houses.
RQ2- How effectively can digital housing co-design tools enable inhabitants to interact with architectural design in an informed manner to realise customised housing?	**H2-** Digital tools enhance collaboration between inhabitants and architects in housing projects by enabling residents to actively participate in design decisions.	**G2-** Define and test an interface solution for the co-design of housing focusing on the user experience.
RQ3- What are the benefits and limitations of inhabitants using a digital design tool in the scope of a co-design process and definition of customised housing?	**H3-** The use of digital tools in the co-design of housing, by enabling housing customisation, contributes to end users' satisfaction in both the design process and the resulting house designs.	**G3-** Gather the perspectives of architects and inhabitants on collaborative housing design, particularly in relation to utilising the proposed graphical user interface.

1.3 Methodology

To achieve the research goals mentioned, a mixed-methodology approach was employed, utilising distinct methods in various phases of the research to collect both qualitative and quantitative data.

The development of this research project followed a Design Science Research Methodology (DSRM) where architecture research was combined with techniques from Human-Computer Interaction (HCI). Design Science Research is a methodology used to solve an identified problem through an iterative process of development and evaluation of an artefact, initially introduced in the area of Information Systems. The methodology, as proposed by the authors (Peffers et al., 2007), is represented in Figure 1. This approach is a problem-solving paradigm for the creation of innovative solutions to real-world problems (vom Brocke et al., 2020). Beyond the Information Systems field, DSRM is a central research paradigm in many other domains, including architecture, engineering, business, and economics (Peffers et al., 2007). Figure 2 summarises the methods and techniques used in this research throughout the Design Science Research Methodology steps. Each step is explained in the following sections.

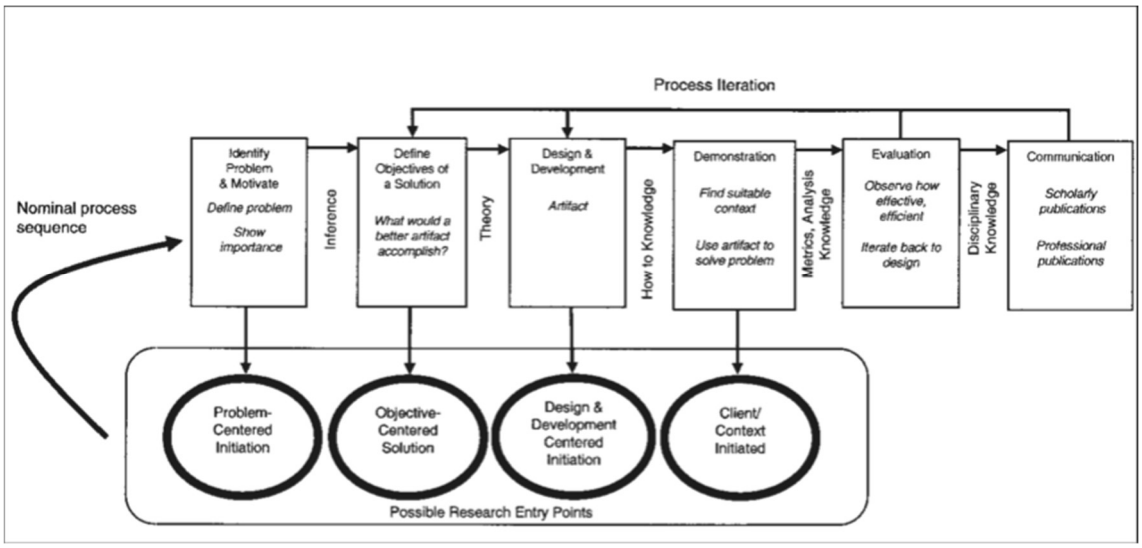


Figure 1_Design Science Research Methodology (DSRM) nominal process ***(Peffers et al., 2007)****.*

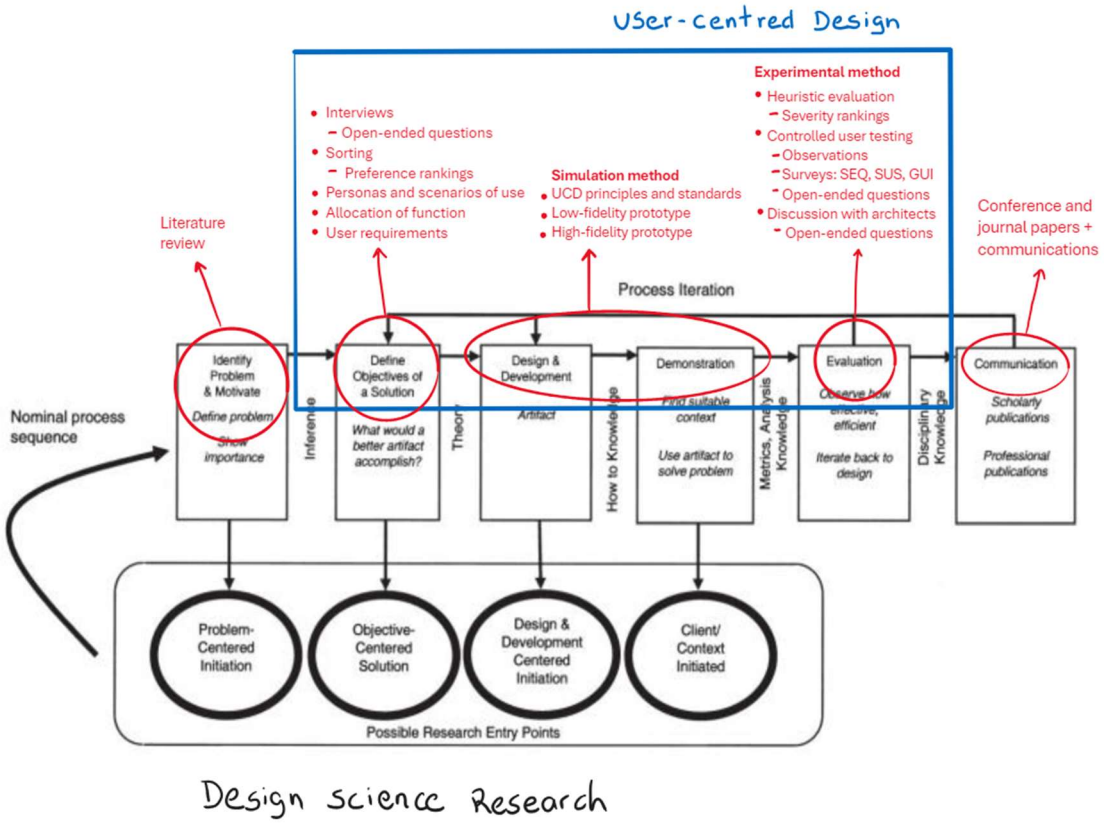


Figure 2_Techniques used in this research for each step of the DSRM. Adapted from (Peffers et al., 2007).

1.3.1 The steps of the DSRM

1.3.1.1 Identify Problem & Motivate

The literature review informed the first step, "Identify Problem & Motivate". The goal of this step was to revise and synthesise the approaches and methods for delivering customised housing design, both analogic and computer-based. The existing approaches for housing customisation were reviewed, as well as the methods used at different levels of participatory and co-design processes. Also, an analysis of existing generative and semi-automatic housing design systems was made. The advantages and disadvantages of these systems are considered to identify their potential to address customisation by inhabitants.

A narrative literature review using a snowball search technique was made, where relevant works on housing customisation and computer-mediated participatory design were used as a starting point to find references on other works related to the topic. Additionally, although the snowball technique is useful for going back in time (Ghent University, 2023), there was also a need to find recent works on the subjects under study. Thus, the thesis used bibliographic databases such as Scopus, Science Direct, Web of Science, Google Scholar, Cumincad, ResearchGate, ACM Digital Library, and other local libraries to search for works published in the last five years. Relevant literature was searched using keywords

such as “housing customisation”, “co-design”, “digital design tool”, “generative design”, “design interface”, GUI and “Graphical User Interface”.

While adhering to the principles of DSRM, the artefact was simultaneously defined and developed under the principles of User-Centred Design (UCD) to accomplish the goal of conducting research with a focus on the user experience. UCD is an iterative design process in which end-users are involved in the development of the design, including the empathy with the specific end-user problem and the design of the right solution for such problem. The main principle is that the user is placed at the centre of the process and has an influence on the way the design is shaped (Abras et al., 2004). The steps “Define objectives of a solution”, “Design and development”, “Demonstration” and “Evaluation”, proposed by DSRM, were carried out based on User-Centred Design principles.

1.3.1.2 Define objectives of a solution

In the step “Define objectives of a solution”, the goal was to define the requirements that enable inhabitants to co-design their houses (**G1**). A group of techniques was used, such as user requirement interviews, sorting, definition of personas and scenarios of use, and allocation of function (Maguire, 2001). Each of these techniques is described below.

Interviews were conducted to identify the potential users' characteristics and collect their needs regarding their participation in the design process of their houses using a digital tool. Professionals from architecture, urbanism, and social sciences were interviewed to gather information on participatory processes and the potential of using digital tools in such processes. Furthermore, housing cooperatives and inhabitants of these institutions (potential users) were interviewed to identify whether and how participation occurs in this specific context and how a digital tool can improve it. The interviews protocol is explained in Chapter 3, including the definition of the population and sample, the experimental method, and the results obtained. The interviews were semi-structured with open-ended questions. According to Maguire (2001), user requirements interviews are usually semi-structured and use fixed questions with scope for the user to expand their responses. Such interviews are useful to explore subjects when the range of responses is not fully known, which was the case. The interviews intended to explore subjects without knowing what the responses would be. Thus, a deductive technique was first used by defining the interview’s questions based on literature and our expertise in architecture. Then, an inductive technique was used based on the new issues that emerged from the interviewees' responses. Besides the open-ended questions, a **sorting** technique was also used in the last part of the interviews with inhabitants. This phase was intended to define aspects of the interface, such as features and types of visualisation, and interaction. A group of images (see 3.5.2.3) of the interfaces of some of the systems analysed in the previous step of the DSRM (“Identify

problem & motivate") were prepared. Such images illustrated the options intended to be introduced to inhabitants, who were asked to sort such options according to their preferences. The options were presented randomly. According to Groat and Wang (2013) similar conditions must be ensured, and random assignment is considered the most effective way of achieving it. The qualitative data explored through the open-ended questions and the preference rankings extracted from the sorting technique were useful to identify the characteristics of potential users and define usage scenarios, which informed the definition of user requirements.

Then, **personas** and **scenarios of use** were defined. A Persona is a description of an imaginary person who represents the characteristics of a group of potential users. Personas represent user profiles of a system and are used to clarify user requirements (Cooper, 1999). Scenarios of use are examples of how users perform tasks. These descriptions help to elucidate the tasks and how they can be carried out by the user before there is an interface solution (Gonçalves et al., 2017). Different scenarios can be described for different personas. In this research, two personas were defined: the architect and the inhabitant. However, the development of the user interface focused on the inhabitant, and therefore, the scenarios were defined for only one persona (inhabitant).

Based on the results of the previously described techniques, the information for the **definition of user requirements** was gathered. Requirements for the co-design of houses, and the interface functional and non-functional requirements were identified, and will be further presented and detailed in section 4.2.

The **allocation of function** was used to organise the tasks that would be performed by the different personas and those performed by the technology itself. Maguire (2001) states that task allocation is useful in systems where there is more than one single user. Although this research focuses on the user interface for inhabitants, it is suitable at this phase to consider the whole framework for context.

1.3.1.3 Design & Development and Demonstration

In the "Design & Development", and "Demonstration" steps of the DSRM, a simulation method was followed, considering UCD principles and interface design guidelines, and using a prototyping technique. The goal was to develop and test a framework focusing on the user experience (**G2**). The design solution was produced considering Norman's design principles (Norman, 2013), Shneiderman's golden rules (Shneiderman & Plaisant, 2005) and Nilsen's heuristics (Nielsen, 1994b, 1994a) addressed in the book "Introdução ao Design de Interfaces[1]" (Gonçalves et al., 2017). Although Norman's and Shneiderman's works were considered, the interface development mainly followed Nielsen's heuristics, since, according to Gonçalves, Fonseca and Campos (2017), are the most used in the

[1] In English: "Introduction to the Design of Interfaces"

academy and industry. Besides design principles, this research also followed other interface design guidelines related to graphic design, the use of colour and text, messages and task distribution (Gonçalves et al., 2017).

Low-fidelity (paper) (Rettig, 1994) and **high-fidelity** (digital) (Interaction Design Foundation - IxDF, 2018) prototypes were developed in different phases of the iterative process. Paper prototyping was used to perform a formative evaluation with potential users in a preliminary phase. Such a technique is used to rapidly identify issues in the initial phases without spending many resources (Rettig, 1994). Paper prototypes are used to test a process instead of a look-and-feel appearance of an interface design. Because they are low fidelity, paper prototypes focus on the sequence of performing tasks rather than on the interface's appearance.

A **high-fidelity prototype** was created using Figma (Figma Inc, 2016), a codeless interface design web tool. High-fidelity prototypes are used to create realistic representations of the interface. They provide an immersive experience that simulates real-world usage, as they are closest to the final product. High-fi prototypes provide accurate user test results as functioning features allow measuring aspects that paper prototypes do not allow, such as the dynamic feedback of the system (Gonçalves et al., 2017; Rudd et al., 1996).

1.3.1.4 Evaluation

The “Evaluation” step of the DSRM was conducted through an experimental method involving three different groups of participants: (1) heuristic evaluation with interface design experts, (2) controlled user testing with representatives of potential users in two different iterations and (3) discussion with architects. In this step, the aim was to address the second and third research goals (**G2** and **G3**) by collecting the perspectives of architects and inhabitants about the proposed co-design tool after they experienced it.

The **heuristic evaluation** involves having a small set of evaluators who examine the interface to find usability problems in a user interface (Nielsen, 1992, 1994b). It informed the refinement of the high-fidelity prototype so that it could be subsequently tested with inhabitants and architects. Five interface design experts were involved in experimenting with a high-fidelity prototype to identify usability issues in the proposed interface and give recommendations for improving it. This evaluation was done according to the ten Nielsen Heuristics (Nielsen, 1994a), and the experts attributed frequency and degrees of severity to the identified usability issues. This attribution allowed the organisation of the issues by priority to solve them before testing the high-fidelity prototype with users.

The **controlled user testing** was conducted in two different iterations in a controlled environment: a formative evaluation with the low-fidelity prototype and a summative evaluation using the high-

fidelity prototype. The former was conducted before creating the high-fidelity prototype and testing it with experts (see Figure 3). Both iterations aimed at gathering information on the system's use by potential end-users. According to Maguire (2001) the benefit of this approach is that the system is tested under conditions closest to its real use (being used by the potential end-users). Various techniques, such as observations, surveys, and open-ended questions, were employed to measure usability and user satisfaction by collecting qualitative and quantitative data.

Observations were used to collect information about task performance and user behaviour during the controlled user testing based on the execution of certain domain specific tasks. Quantitative data was collected through usability measures such as effectiveness and efficiency, measured through task performance observation. During the observations, the researcher noted the number of tasks completed, the number of attempts, and the amount of time needed to complete them. Both iterations used the same techniques and instruments to collect the information. However, in the formative evaluation with the low-fidelity prototype, the efficiency was not measured because, as mentioned before, the paper prototype does not allow the measurement of the dynamic feedback of the tool.

Qualitative data was also collected during the observations by asking participants to "think out loud" and observing their behaviour to identify when they experienced difficulties. A video recording assisted in this task, helping the researcher to revise the experience for accurate results.

Surveys were used to collect quantitative data regarding the interface usability and user satisfaction. The participants filled out standardised questionnaires during and after the interface experimentation. As this approach is subject to the subjectivity of the participants' interpretation, the results are compared with the observations of task performance.

During the experience, the participants filled out a Single Ease Question (SEQ) questionnaire rating each task after completing it. This questionnaire is used immediately after the task completion, when the experience is still fresh in memory, to assess how the user perceived the just attempted task experience regarding the easiness of performance. This questionnaire is reliable across any level of fidelity (Sauro, 2018).

After the experience, a System Usability Scale (SUS) questionnaire (Brooke, 1995) was used to assess the interface's usability. The questionnaire consists of ten predefined statements alternately phrased positively and negatively, to be rated from 1 to 5 (totally disagree to totally agree).

A Graphical User Interface (GUI) questionnaire was also provided to assess aspects related to the interface elements, such as buttons, dialogues, menu navigation, etc. Nine statements were defined to be rated also on a Likert scale from 1 to 5, similar to the SUS questionnaire.

Finally, **open-ended questions** were also made after the experience to collect qualitative data regarding user satisfaction. Participants were asked to list the interface's three strong and weak

aspects in their opinion. Post-experience interviews are a quick way to obtain subjective feedback from users (Maguire, 2001). Such feedback allows us to identify opportunities for improvement based on user satisfaction that goes beyond the usability measures.

The last group involved in the evaluation consisted of architects. Although they have been involved in experimenting with the interface under the same conditions as potential users (inhabitants), only open-ended questions were asked to them, to collect qualitative data during the **discussion with architects**. Their involvement aimed to elicit expert insights into the benefits and limitations of inhabitants using this design tool within the scope of a co-design process and definition of customised housing.

1.3.1.5 Communication

Finally, the "Communication" step of the DSRM was addressed during the research development. To disseminate the results of each step, conference and scientific journal papers were prepared, and communications were made at several scientific and non-scientific events.

The results of the analysis of a group of housing customisation systems were published and presented at the 38th edition of the eCAADe international conference (Raposo & Eloy, 2020) .

The results of the interviews and the definition of user requirements were published at the Archnet-IJAR (Scopus Q1) journal (Raposo et al., 2024b), a poster was presented at the 22th edition of the international conference of the Portuguese Association of Information Systems (CAPSI - Conferência da Associação Portuguesa de Sistemas de Informação), with publication of an abstract in the book of abstracts (Raposo et al., 2022b), and a communication was made at the 27th edition of the International Association People-Environment Studies (IAPS) conference, with publication in the book of abstracts (Raposo & Eloy, 2022).

The results of the first version of the interface's definition and first iteration with the low-fidelity prototype were published and presented at the IHCI- Interfaces and Human-Computer Interaction international conference (Raposo et al., 2023a).

The results of the last two iterations with the refined interface and high-fidelity prototype are published in PLoS One (WoS / Scopus Q1) journal (Raposo et al., 2024a).

Other complementary works related to citizen participation in design projects and housing customisation were also published and presented (Eloy et al., 2021b, 2021a; Raposo, Eloy and Dias, 2022; Ng et al., 2024; Eloy, Raposo and da Silva, 2025).

1.3.2 Iterative process

Considering the framework of the DSRM and UCD methodologies, and the methods and techniques explained above, Figure 3 illustrates the ten-step methodology followed for the definition and testing

of the graphical user interface through four iterations. The steps followed are (1) interviews, (2) definition of user requirements, (3) definition of the interface's features, (4) definition of the graphical user interface, (5) formative user evaluation, (6) interface refinement, (7) heuristic expert evaluation, (8) second interface refinement, (9) summative user evaluation, and (10) architecture expert discussion.

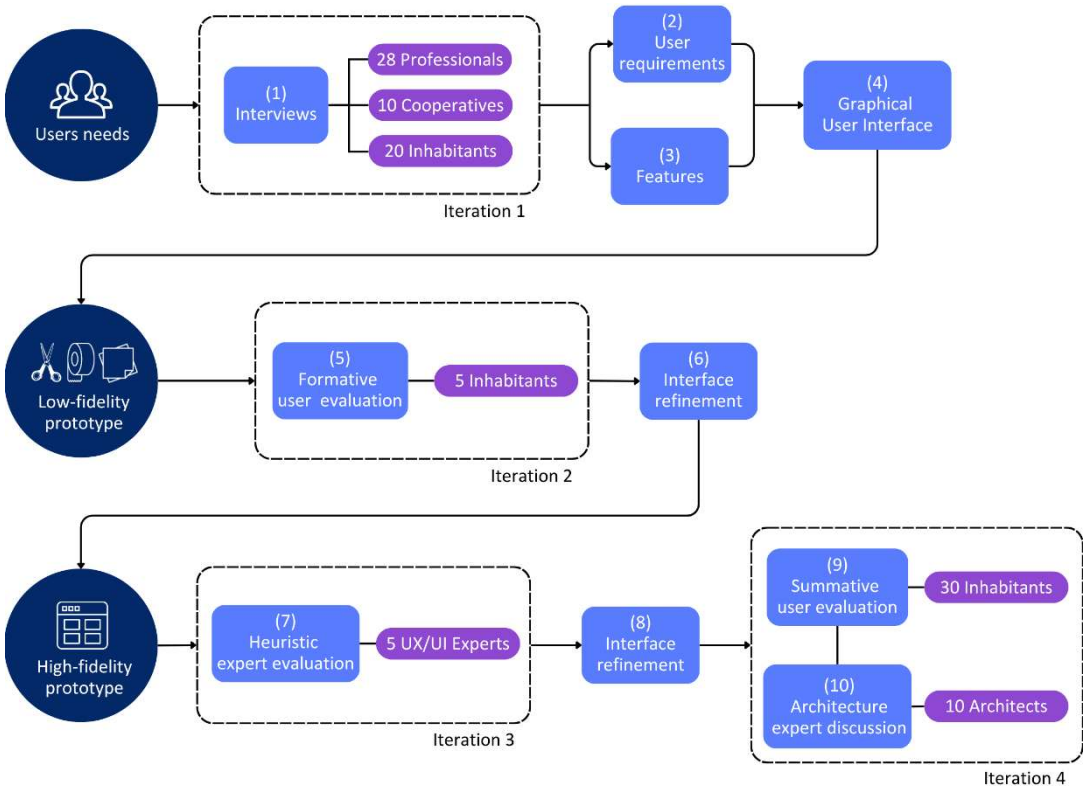


Figure 3_Sequence of steps followed for defining and testing the Graphical User Interface, identifying the iterative process

The first iteration involved collecting users' needs through interviews (step 1) with twenty-eight professionals, ten cooperatives and twenty inhabitants. Professionals from architecture, urbanism, and social sciences were interviewed to gather information on participatory processes and the potential of using digital tools. Furthermore, housing cooperatives and inhabitants of these institutions (the potential users) were interviewed to identify how participation occurred in this specific context and how a digital tool could have improved it. The research focused on housing cooperatives as an example of a multi-family housing context, which would benefit from the proposed interface.

The results allowed the extraction of the user requirements (step 2) for the interface definition. Based on these requirements, the interface's features were defined (step 3), enabling the design of the graphical interface with which users interact (step 4). In the second iteration, a low-fidelity paper prototype was tested in a formative evaluation (step 5) with five potential users (inhabitants). According to their feedback regarding their satisfaction and the interface's usability, the interface was refined, and a high-fidelity prototype was created to be tested again (step 6). In step 7, the third

iteration was conducted by performing a heuristic evaluation of the high-fidelity prototype with five interface design experts to identify and correct issues that potential users could possibly face. In step 8 a second interface refinement was made by correcting the issues identified by experts in the previous step. The research proceeded to the fourth iteration, which included steps 9 and 10. In step 9, a summative evaluation was performed with a larger number of potential users (30 inhabitants). Finally, in step 10, a group of 10 architects commented on the system after using the interface prototype to discuss, from their architectural expert point of view, the use of such a tool in a co-design process.

1.3.3 Data collection and analysis

Both qualitative and quantitative data were gathered during different phases of the research. Qualitative data was collected from the interviews used to define the users' needs, the observation of user behaviour during the interface experimentation in the user studies, and the post-experience open-ended questions made to inhabitants and architects. The results were analysed using a content analysis method, where patterns were identified regarding the frequency with which participants shared the same opinion, although using different terms to refer to the same idea.

The heuristic evaluation collected both qualitative and quantitative data, including the identification of usability problems and the recommendations for improvement (qualitative), and the severity and frequency measures (quantitative). The analysis of these results generated priority rankings.

On the other hand, quantitative data was collected during the interviews from the sorting technique, which generated preference rankings, and during the user studies, from the observation of task performance and the three administered questionnaires. This data was analysed using a descriptive statistical analysis method, where average and standard deviation measures were calculated. The SUS questionnaire has a specific analysis method, further explained in section 5.1 (Formative evaluation using a low-fidelity prototype).

1.4 Structure of this thesis

This work is divided into six chapters.

Chapter 1 provides an introduction to the thesis research, outlining the problem statement, the raised research questions, the hypotheses and the goals of the research. Additionally, a detailed description of the methodology is provided, including the techniques used in each step and the methods for data analysis.

Chapter 2 provides an overview of the literature on housing customisation by inhabitants. It starts by introducing the problem of unsuitable houses to inhabitants' needs and describes strategies that

have been implemented for housing customisation. Then the chapter delves into the topic of participatory and co-design processes, discussing these processes in architecture and highlighting relevant case studies. Furthermore, the use of digital technologies in co-design processes is explored, and it concludes with a review of computer-mediated participatory design tools, where a group of computational systems are analysed.

Chapter 3 refers to the results of interviews made as part of the methodology followed, where three different groups were interviewed to gather information on participatory processes that occurred and how they can be improved with digital technologies. This information allows to collect the users' needs for a Graphical User Interface for the co-design of housing.

Chapter 4 describes the GUI proposal, starting with the definition of user requirements that were informed by the interviews' results. This then details the GUI proposal development, including the description of potential end-users and usage scenarios, the GUI description of the proposed tasks, underlying the structure of the interface, and the Graphical User Interface.

Chapter 5 presents the results of prototyping and testing the proposed interface involving different groups of participants. Each experience is described, including the protocol, the data gathered through the used techniques, and also an analysis and discussion of the results is provided.

Finally, in Chapter 6, conclusions are presented. The research questions and the formulated hypotheses are retrieved and compared with the results of the previous chapter. Furthermore, this chapter emphasises the contributions of this research and identifies its limitations, suggesting paths for future work.

CHAPTER 2: Literature Review

2.1 From uniformity to diversity: addressing community diversity through customised housing

Urban environments are inhabited by a highly diverse population, characterised by different needs and preferences. Residents' satisfaction with their dwellings is closely linked to the extent to which housing is tailored to their specific requirements. Nevertheless, a significant gap persists in the existing literature concerning the provision of customised housing—reflecting not only a gap in scholarship but also a corresponding gap in design.

This sub-chapter addresses this lack of customisation, which stems from large-scale, standardised, and impersonal housing production that fails to reflect population diversity and the demographic changes that unfold over time. It explores strategies for housing customisation through inhabitants' involvement in the decision-making process regarding the configuration of their dwellings. The sub-chapter also considers the role of housing cooperatives, particularly their potential to promote affordability and social cohesion through democratic decision-making and collaborative approaches to design and management.

2.1.1 The meaning of housing

In architecture, meeting the diversity of end-users' needs and desires can be challenging. However, end-users' satisfaction with the built environment depends on how the space suits their specific needs. This is particularly important for housing design. Housing is an essential good, and its customisation greatly influences people's quality of life (Adeyemo et al., 2024; Güngör & Terzi, 2024; Yavari et al., 2015), which is paramount for a successful design (Lekjep, 2017).

Abraham Maslow's Hierarchy of Needs, originally published in his well-known work *The Theory of Human Motivation (Maslow, 1943),* is a motivational and human behaviour theory in psychology that defines the basic needs for human satisfaction and quality of life. The five categories (physiological; safety and security; love and belonging; self-esteem; and self-actualization) are represented by a pyramid whose base represents the most fundamental needs. Lower-level basic needs like food, sleep and shelter must be met before higher needs can be fulfilled, although it is not a strict linear progression.

The first level refers to physiological survival needs such as breathing, food, water, shelter, clothing and sleep. The levels become increasingly psychological and intellectually oriented and are long-term achievements. Second-level needs are related to safety and security (such as financial

security), physical safety (such as health and protection from injury or danger) and safe environments with laws and order for social stability. Love and belonging refers to social connections and relationships, which include family bonds, friendship and a sense of belonging and acceptance in social groups or communities. Esteem needs are related to self-achievement, as well as reputation, recognition, and appreciation from others, as humans need to feel valued and accomplished. Finally, self-actualisation needs are at the highest level of Maslow's hierarchy, and they explore self-potential, skills, and personal growth.

Although Maslow built upon his original hierarchy and later included new levels (Cognitive, Aesthetic, and Transcendence needs) (McLeod, 2024), the shelter has remained part of the basic needs. This means that housing is one of the most important needs of human beings. Housing has two important dimensions that respond to the three lower-level needs from Maslow's hierarchy: physical and social dimensions, i.e., housing explores the experiential and social dimensions of architecture and reflects different lifestyles, cultures and ethnicities of contemporary society (Charalambous, 2017). The physical dimension refers to housing materiality as shelter. The social dimension is real estate ownership as a space of personal privacy and security where family life takes place. Also, the housing location plays a role in access to social status and belonging to a community. The neighbourhood influences the quality of life and the social status of the residents (Brandsen & Helderman, 2012). Van Weesep (2000) stresses that providing quality and affordable housing for marginalised social groups is a housing strategy that gives the place an image of a secure and inequality-free environment, making it appealing to investors and enhancing its economic development. Consequently, these groups are integrated into the community and have access to work opportunities and local services and facilities. The author further adds that the attractiveness of housing is related to the environment in which it is located, as many people are influenced by the physical and social aspects of a neighbourhood when looking for a house.

The literature (Adeyemo et al., 2024; Güngör & Terzi, 2024; Matyášová, 2018) reinforces this idea by discussing the influence of proximity to work and local services on residential satisfaction, as well as the social factors such as relationships with neighbours and community cohesion. According to Adeyemo *et al* (2024), residential satisfaction is the degree of satisfaction that a housing framework gives to an individual. It is based on the relationship between the inhabitant's expectation that the house will satisfy their requirements and what the house really provides and satisfies. It implies not only the spatial characteristics of the housing but also the social aspects that give a sense of community. According to the author, such sense is represented by social ties within the community, which increases psychological satisfaction and decreases the willingness to move.

Some studies, such as the ones conducted in the Czech Republic by Jana Matyášová (2018), Turkey by Güngör and Terzi (2024), and Nigeria by Adeyemo *et al.* (2024) assessed residential satisfaction in

housing contexts with different characteristics. These studies show that good transportation and proximity to work, local amenities and services are highly rated in terms of residential satisfaction. However, residents are not satisfied when housing is located in city centres, as it generally fails to meet important criteria such as space and layout of housing, lack of parking and green areas, among other aspects. As Güngör and Terzi (2024) found in their study, which assesses the perceived satisfaction with the quality of life in eight different density housing type neighbourhoods in Kayseri (Turkey), people have a preference for living in low-rise housing types. The study involved the evaluation of a series of criteria regarding the housing, neighbourhood and city levels. The results show that, although inhabitants of single-family house types have less access to transportation services and access to the neighbourhood and urban amenities, they show higher satisfaction levels regarding housing features and overall quality of life than high-rise housing inhabitants. However, Güngör and Terzi argue that cultural and demographic differences affect the perception of quality of life and, thus, residential satisfaction.

Accordingly, Matyášová (2018) states that satisfaction depends on each person's criteria, and the criteria depend on the characteristics of the inhabitants themselves. The author states that income and age are examples of aspects that determine each one's requirements, as people with higher income, for instance, have the ability to choose where to live, whereas older people are more concerned with the connection to the place. Adeyemo *et al.* (2024) studied residential satisfaction through criteria related to the housing location, design characteristics and structural characteristics and found that age has an impact on determining the criteria that influence inhabitants' satisfaction. The authors show in their study that older people are less satisfied with their housing environment, arguing that they want to be closer to family and local traditions and to live in environments where they can carry out their activities in a less stressful way. They also argue that new housing developments should consider their inhabitants' future needs.

These studies show that satisfaction depends on how the housing suits the inhabitant's needs since each inhabitant has specific requirements that are determined by their characteristics, such as age, affordability, or other aspects.

2.1.2 The urgent need for mass-produced housing

Cities are increasingly becoming multicultural environments in which the characteristics and needs of the inhabitants differ. Housing provision must respond to different demands, and to the changing needs of inhabitants over time, resulting from demographic transformations (Adeyemo et al., 2024; Wan et al., 2010). The housing sector is influenced by forces that affect cities and governments' housing provision capacity. Due to the need to respond quickly to a large demand, standard housing, i.e., housing with the same spatial characteristics, is constructed, making it unsuitable for population

diversity and its demands. Examples of such forces are the displacement of population masses and natural disasters that require quick housing provision or replacement of housing stock.

The globalization and urban growth greatly influence the housing shortage in cities. According to Charalambous (2017), migratory masses, including internal labour population displacements and the movements of refugees, greatly impact the diversity and increase of population in urban societies. These flows cause challenges such as "housing accessibility and affordability, homelessness, overcrowding, social integration and community building, among others" (Charalambous, 2017, p. 153). In Romania, for instance, although there are social programmes aimed at providing affordable housing to the most vulnerable groups of the population, the demand is so high that a large part of the population is unable to access these social programs (Neijenhuis, 2017). Also in Switzerland, a neoliberal country, public housing is not widely practiced. It is only practiced in large cities such as Zurich. However, access to public housing programs or social subsidies is limited to individuals who meet certain criteria, which leaves a large part of the population without access to affordable housing through government aid (Balmer & Gerber, 2017). To have a shelter, people with low incomes organise into informal settlements built by themselves with poor conditions (Herda, 2017a; Neijenhuis, 2017; Noguchi & Hernàndez-Velasco, 2005). Benrós *et al.*, (2011) state that these settlements lead to the rise of urban slums in many big cities, which frequently fail to meet the sanitary and spatial standards necessary to ensure decent living conditions for the population.

The urgent need to provide proper housing to people in such situations is challenging, and governments need help from private investors to face such challenges. An example was the situation of Portugal during the second half of the 19th century and the beginning of the 20th century. Due to the increasing industrial activity, the country faced a significant growing population in the capital and other urban areas. The growing need for labour in the construction industry encouraged the migration of rural workers to the city in search of employment and better living conditions, leading to a serious housing shortage. According to Ildefonso *et al.*, (2019), the new inhabitants, driven by poverty, improvised shelter, however, unsanitary conditions caused many deaths and a high vulnerability to diseases due to the lack of sunlight, the concentration of humidity, and the saturation of the air. The need to create minimum living conditions, led to the construction of working-class neighbourhoods (called "Bairros operários"), by the initiative of private companies that provided housing for their workers, with better living standards that increased according to the worker's position (Ildefonso et al., 2019).

Later, in the 70s, there was a change in housing policies triggered by the revolution of 25th April, 1974. The population was poor, and the rate of precariousness was still very high. The SAAL process ("Serviço de Apoio Ambulatório Local") (Local Ambulatory Support Service) emerged as a response to this housing deficit in an attempt to combat the illegal settlements caused by the displacement of rural

migrants since 1930 and worsened by the arrival of returnee immigrants from the colonies as a result of the revolution (Sardo, 2014). The SAAL was created to combat housing precariousness and promote citizen participation in the design process of neighbourhoods, ensuring the right to appropriate living conditions and suitable to their residents. According to Bandeirinha (2011), although the process had significant national and international impact, the large volume of operations taking place simultaneously from north to south of the country led to significant delays in construction due to lack of funds and technical support, as well as the difficulty of temporarily rehousing populations displaced from slums or former colonies. This lack of capacity from the state to keep up with the pace of operations led to the suspension of the process in 1976, on the grounds that the technical brigades had deviated from the spirit of SAAL, with a lack of social participation, and that the number of houses built until then was not significant (Bandeirinha, 2011).

Currently, there is still a high demand for affordable housing in Portugal due to the rising cost of living, worsened by phenomena such as the Covid19 pandemic, speculation and short-term rentals. The entry of many immigrants into the country has increased the demand for housing, causing the resurgence of irregular settlements, where people live in precarious conditions (Antunes, 2019). On the other hand, there is a high rate of young emigrants who cannot afford the housing costs in Portugal and therefore seek better living conditions abroad.

2.1.3 The access to affordable housing

The efforts to provide decent housing for the most needy raises the discussion about the rights of access to housing for other social groups. Wan, Hanif and Singaravello, (2010) argue that while there are policies aimed at providing housing for the poorest, little attention is given to the needs of the middle-income group. Van Weesep (2000) states that the conditions for acquiring homeownership vary by country, and in several European countries, social housing policies take different forms. The author mentions that in Sweden, almost half of the social housing was built by cooperatives, which requires investment from the inhabitants, while in Great Britain and France, housing was privatised with programmes subsidising the acquisition for the poorest. In the Netherlands, on the other hand, most of the social housing was represented by housing rentals owned by associations, thus allowing people with the lowest incomes to access low rents (Van Weesep, 2000). In developing countries, there are also inequalities regarding access to housing. Whereas there are successful efforts to reduce housing shortage and improve living conditions for the low-income in Brazil, Ethiopia and Uruguay (Herda, 2017; Neijenhuis, 2017), Malaysia is an example of how middle-income groups are impaired. Wan, Hanif and Singaravello (2010) conducted a study in which they assessed the level of affordability of middle-income groups in several cities in Malaysia and concluded that, although income is higher in larger cities, housing is not affordable for middle-income groups since they are not covered by social

programs and are also unable to compete with the regular market prices. The authors define affordable housing as the balance between house prices and other costs, considering the residents' income. The location of houses influences determining affordability, as residents' incomes must also cover transportation costs to work and access to various services.

Gentrification is also causing the displacement of populations from city centres in different European cities such as Milan, Budapest and Istanbul, caused by the investment in city properties for profit instead of affordable residential areas (Csanádi & Csizmady, 2017). Csanádi and Csizmady (2017) refer to gentrification as a change in the land use in city centres. Investors, either private or the governments themselves, choose to invest in properties where they believe there is potential for profit, increasing property prices and turning them unaffordable. In Italy, the rise in the prices led people who were able to afford housing to seek social support because they could no longer afford housing costs (Boschi, 2017). However, it is necessary to meet certain conditions and requirements to fit the profile eligible for targeted social housing programs (Neijenhuis, 2017). The housing provision in cities is not sufficient, not giving the middle-low and middle-income groups opportunities to have access to housing in the city centres. The issue of housing accessibility becomes critical for these groups since their financial constraints not only hinder their ability to become homeowners but also limit the size and type of houses they can afford to purchase.

2.1.4 Housing unsuitability and lack of appropriation

The success of a design in architecture does not rely solely on time efficiency, cost or aesthetics, but rather on user satisfaction. Succeeding in the task of designing to accommodate a large population and doing it quickly, and using standards to optimise costs, does not guarantee the success of the operation. According to Plowright and Cole (2012), task completion and productivity assessment are of little relevance to architectural design success, although they are used in other areas to measure performance. Rather, Lekjep (2017) shows that user satisfaction is a critical factor in evaluating the success of architectural designs. His research underscores the significance of understanding users' needs and preferences to create successful architectural spaces. Thus, the inhabitants' satisfaction does not only lie in their access to housing but also in the fact that the houses must be customised to meet their individual needs. According to Salama (2011), affordability is often perceived as contradictory to design quality and the ability to meet inhabitants' needs, and thus, affordable housing focuses on cost efficiency and excludes the social aspects and other transdisciplinary knowledge that creating affordable housing involves.

After the Second World War, many European cities saw their housing stock destroyed due to air raids and a significant part was rebuilt with similar characteristics, creating uniform, monotonous and impersonal environments (Benrós & Duarte, 2009; Treija et al., 2017). Benrós et al., state that these

environments were produced “based on the idea of mass production that one size fits all. **This response fails to meet the individual and cultural needs of the population**, even if it provides desirable sanitary conditions” (Benrós et al., 2011, p. 248).

The lack of customised housing is exemplified by the mass production of housing in Turkey following the 2000 earthquake led to the construction of houses with ‘typical designs’ that proved to be inadequate to residents’ expectations, causing dissatisfaction with the housing solution provided. Davidson *et al.* (2007) report that, for various reasons, this dissatisfaction led to people not occupying the houses or abandoning them quickly. Those that are not vacant have undergone major changes. Noguchi and Hernàndez-Velasco (2005) refer that when residents feel unsatisfied, they feel the need to make major changes to their houses after moving in to adapt them to their needs. However, due to their economic conditions, these changes can take several years to complete.

The unsuitability of housing for its inhabitants also occurs due to factors that arise over time, as the changing needs of the population. A study on housing post-occupancy modifications among the middle-income group in India was conducted by Chawla and Gupta (2023) to assess if houses fit inhabitants' needs over time. The study reveals that more than half of the interviewed residents made unauthorised changes to their houses, and 75% said they would make more changes if they were allowed by bylaws. These numbers indicate the dissatisfaction of inhabitants with their houses as they no longer meet their needs. The authors suggest that houses should be flexible to accommodate the evolving needs of the occupants.

Another cause of the change in inhabitants' needs is demographic changes occurring in the cities. Even if housing could be considered adequate for its inhabitants at a given time, demographic changes that occur in cities over time cause changing needs, making the housing stock outdated and unsuitable for the new circumstances. Diaconu et al (2017), made a comparative study between four European urban areas - Lisbon (Portugal), Dublin (Ireland), Paris Region and Saint-Étienne (France), which face demographic changes or are increasing in population. The authors discuss the public authorities’ level of involvement in housing supply to address the challenges these cities face due to demographic trends. The study highlights that demographic shifts, such as population growth and smaller household sizes, are driving the need to restructure housing in Lisbon, Dublin, and the Paris Region. The way public authorities respond to the challenges of demographic change differs in each country. According Diaconu et al., (2017), France invests in adapting housing to meet evolving needs, while Portugal and Dublin rely heavily on the private sector, which invests in more profitable housing types, often neglecting necessary changes to the housing stock. In Paris, efforts to densify urban areas to preserve agricultural areas have sparked community dissatisfaction, prompting suggestions to expand into surrounding areas and improve transport infrastructure.

Community dissatisfaction, as mentioned before, can lead to housing abandonment, degrading urban centres and requiring urban restructuring. Charalambous (2017) stresses that the experience of urban life became unstable and fragmented, contrasting with concepts of permanence and sense of belonging that were previously associated with living in cities. Either due to demographic changes or due to standard housing provision, the houses that are not aligned with inhabitants' needs do not provide them with the feeling of appropriation.

The literature refers to the term “appropriation” in different ways, depending on the context. In psychology and urban studies, appropriation can refer to personal property and the act of customising and adapting something to meet one’s needs. Personal property is the feeling of claiming something as one’s own, taking ownership or control over something, as personal belongings and intellectual or cultural property (Cattien & Stopford, 2022). The process of individuals or groups customising a space or object brings the feeling of ownership over a task or project. In housing design, customisation turns the space tailored to the inhabitants’ needs, fostering satisfaction and resulting in a sense of accomplishment and pride over the outcome, as it is a result of their decisions and actions. This process of appropriation results in a stronger sense of identity and attachment to their environment (Elizondo, 2024). Accordingly, Treija, Bratuškins and Bondars state that by “constructing, decorating, furnishing, maintaining, and restoring their homes” (Treija et al., 2017, p. 239), people shape customised environments, developing a sense of identity with the places they inhabit.

The maintenance is highly related to place attachment, i.e, the affective connection that makes people feel responsibility for the place and a tendency to stay close to it (Dang & Weiss, 2021). The uniformity of mass housing estates constructed in response to the housing shortage has become obsolete with social diversity and new housing patterns. This has brought challenges such as the abandonment and degradation of urban centres resulting from the lack of appropriation and, consequently, inadequate maintenance. Despite some efforts to improve the image of cities, there was no interest on the part of the population in participating in urban regeneration operations due to a lack of attachment to the place (Papa et al., 2017). However, involving the community in the regeneration of residential areas promotes a safe and revitalised environment allowing for the creation of ties between community members, strengthening attachment to the place and promoting concern for maintenance (Park et al., 2025).

2.1.5 End-users involvement in housing customisation

Besides the concepts of appropriation and attachment, the sense of belonging highly contributes to the satisfaction of inhabitants with their living environments. The sense of belonging is defined by the relationship with other people and the feeling of being part of a community. This concept refers

to the third category of Maslow's hierarchy, which, as mentioned before, refers to the social and affective connections within groups or communities (Maslow, 1943; McLeod, 2024).

The community's participation in customising their living environments fosters a sense of belonging. The social interactions during the decision-making process strengthen community bonds, attachment and satisfaction with the place and, therefore, its success. One cannot refer to community involvement in decision-making processes without referring to Lefebvre's concept of the *Right to the City* (Lefebvre, 1996). Lefebvre argued that cities are not just physical spaces, but also the social interactions and activities of the people who use them. The *Right to the City* challenges government dominance over urban planning, which prioritises profit over the residents' needs. The concept refers to the democratisation of urban decision-making and the inclusion of marginalised communities, namely the working class. Lefebvre suggests the possibility of participating in the decisions that determine the design of the spaces, especially by those who daily inhabit them, to satisfy the inhabitants' needs and foster human connections rather than just serving economic interests. According to King (2019), the concept has influenced diverse activist movements worldwide who fought for the marginalised groups, claiming their right to the city. Also, several authors invoke the *Right to the City* in the discussion on democratisation in political processes of urban development and understanding of common interests (King, 2019). On the other hand, there are also scepticisms regarding the right to the city, such as Purcell's criticisms, that point out that it is not clear what the implications of implementing this theory are, and its exclusion of other social groups besides the working class (Purcell, 2002).

Lefebvre's concept has gained attention not only in the context of public space, but also extends to the housing crisis. Lefebvre calls for affordable housing and an end to speculative real estate practices. Similarly to the right to the city, it is also necessary to democratise the right to housing, involving residents in the decision-making process to customise housing and create spaces aligned with their needs.

Personalisation is defined as the act of making and changing something to fit one's needs. Jusan and Sulaiman (2005) state that by personalising a space, people impose control over an environment. Personalising housing is a continuous process as residents' needs constantly change (Jusan and Sulaiman, 2005). Yavari, Vale and Khajehzadeh (2015) highlight the importance of personalisation in housing, as occupant satisfaction leads to a healthy society, and their satisfaction depends on personalisation. The authors also mention that people personalise their living environments for various purposes such as adapting their houses to the family's requirements and activities of their interests, for physical and psychological safety, and changing finishes for aesthetic reasons and achieving better quality. However, as Jusan and Sulaiman (2005) note, personalisation depends on constraints such as regulations, financial constraints and inhabitants' values, such as cultural ones.

Although often used interchangeably, personalisation and customisation have distinct meanings. Both approaches aim to deliver solutions aligned with the user's needs or interests, but the difference lies in who controls the experience. According to Schade (2016) customisation occurs when the user actively makes changes to a product, service, or interface to suit their preferences or needs. In contrast, personalisation occurs when a system or company automatically adapts the user's experience based on collected data such as behaviour, preferences, or demographics. The latter does not require the user's direct input, as algorithms or rules are used to deliver tailored content, recommendations, or features.

The possibilities of creating diverse designs that meet the inhabitants' needs and satisfy their preferences have been studied by several authors and practitioners, who have developed approaches that involve end-users in the decision-making process for their living environments, which cover diverse contexts ranging from design and construction to post-occupancy. These approaches are based on participatory processes, collaborative design and construction, as well as on the concepts of flexibility and modularity.

2.1.5.1 Housing customisation from initial phases with inhabitants' involvement in design and construction

Participatory design emerged in the 60s with the intention of creating a customised and user-centric approach to housing design. Such an approach to architectural design concerns the active involvement of end-users in the design process, allowing them to contribute with their ideas and feedback to create solutions that meet their needs. Inhabitants' participation in the design process ensures that the dwellings meet the users' needs and preferences, leading to more satisfied homeowners and a better quality of living (Önder, Köseoglu and Bilen, 2010). Participatory design has several benefits, including increasing user satisfaction, a sense of belonging, and community empowerment (Marschall, 1998; Sanoff, 2008).

Mihaela Zamfir refers to community architecture as "the built environment that offers itself for community use or stimulates the community participation, in a profound social, inclusive sense" (Mihaela Zamfir, 2015, p. 101) and states that "the community architect gives an increasing importance to the social values" (Mihaela Zamfir, 2015, p. 103). The author notes that community is an interdisciplinary concept (studied in different fields such as sociology, psychology, urban studies, and architecture) based on communication and sharing ideas and information. This interdisciplinary and social component is connected to participatory design, where individuals with diverse backgrounds and skills collaborate to share their knowledge to pursue a common goal.

Participatory design is applied in various fields, e.g. education, public services facilities, public space, and housing. This practice is also vast in scope, covering small and large-scale projects.

Participatory design has been particularly successful in affordable housing projects across the world in countries such as Colombia (Davidson *et al.*, 2007), Turkey (Önder, Köseoglu and Bilen, 2010), and Palestine (Ammar, Hj Ali and Yusof, 2013). In such examples, end-users were involved in the design and construction of their houses. These cases demonstrate that when residents actively engage in the design and construction process, outcomes are more responsive to their needs, cost-effective, and yield higher satisfaction levels, with fewer post-occupancy modifications.

In Portugal, participatory housing initiatives in the early 1970s, such as the SAAL programme and the PRODAC neighbourhood, exemplify efforts to involve residents in the design and construction of their houses. Established in 1974, after the Revolution, SAAL promoted collaboration between inhabitants, multidisciplinary technical teams, and the State to deliver housing solutions tailored to user needs and preferences (Bandeirinha, 2011; Sardo, 2014). Similarly, the PRODAC neighbourhood enabled self-construction with support from the PRODAC Association (Association for Productivity in Self-Construction), facilitating the relocation of residents from informal settlements and later advocating for property rights and public space improvements (Machado, 2018).

A similar community-driven approach can be observed in Burkina Faso, where the Francis Kéré Foundation supported residents of Gando who collectively participate in the construction of primary schools and teachers' housing (Studio Francis Kéré GmbH and Kéré Architecture GmbH, 2001, 2004). In these projects, participation is embedded throughout the process, since the community is involved from the early definition of needs to hands-on construction. Kéré begins by engaging the community in identifying needs and priorities, co-defining the programme and discussing climatic and material constraints. This early-stage dialogue ensures that the architectural response genuinely emerges from local expectations and lived realities rather than being externally imposed. The construction phase includes hands-on training in earth-based techniques, enabling residents to acquire technical skills while contributing directly to the building process (Kéré Foundation e.V., 2026). Through this participatory model, with iterative dialogue between design and construction and the integration of local knowledge into architectural solutions, the projects deliver low-cost climate-responsive buildings adapted to local needs while strengthening skills, social cohesion and collective ownership (Nannini, 2024).

The construction of houses by inhabitants has also been a long-term practice in developing countries. The concept of Self-help emerged in the 1960s, acknowledging the low-income community traditions of constructing their houses using local materials to access low-cost housing. In this approach, communities, on their own initiative, take responsibility for housing development. They are involved in all aspects of house construction (even in the design process) by their own means and workforce. The term *Self-help* originates from foundational texts in the literature, notably John Turner's work (Turner, 1967), which emphasises inhabitants' control over the housing development,

enabling them to build their dwellings incrementally in accordance with their available resources and evolving needs. Turner believes that housing created by the community, which organises itself in voluntary associations, responds better to the needs of the inhabitants and the local culture (Turner, 1967). According to the author, modern housing standards, with their minimum areas and comfort standards, are unsuitable for populations in developing countries, which often lack the initial economic means to achieve them. These populations are more concerned with having secure possession of a place to live than with the minimum quality of housing, preferring large unfinished spaces that can be adapted as their resources allow, rather than minimal finished spaces (Turner, 1967). Accordingly, Bredenoord (2017) states that many families build and improve their houses over the years, being able to decide when the house will be improved. Turner highlights the advantages of this "Progressive Development" of popular settlements over "Instant Development" imposed by official processes based on his experience with self-help processes in Latin America, such as the case of Pampa de Cuevas in the outskirts of Lima, Peru. The inhabitants built the perimeter walls of the house, leaving large spaces inside that would later be compartmentalised and finished. The result is houses that are much larger and more affordable than the government-provided minimum standard houses, which leave many people on a long waiting list when they could have basic constructions that can be improved over time (Turner, 1967).

From the perspective of the local government, there are often concerns about the quality of the self-built houses and extensions (Bredenoord, 2017). However, within the Self-help concept, there have been different projects in which architects give technical assistance to the inhabitants, such as the Community Architect Program created in Cuba in 1993 by the NGO Habitat Cuba, intending to provide technical assistance to the community to construct their own houses (Valladares, 2013). The project involved the community in the decision-making process with the assistance of architects, for them to make informed decisions and shape their houses according to their needs, instead of other self-claimed participatory processes that only involved inhabitants in the construction as a labour force (Davidson *et al.*, 2007). Valladares (2013) notes that Self-help is adequate for developing countries as this approach and the use of local materials is cheaper. However, success depends on technical assistance to help residents participate in the various aspects of housing development, assisting with legal and regulatory aspects. Moreover, Noguchi (2005) highlights that besides the economic aspect, in Self-help initiatives, the inhabitants design their own houses and, therefore, the design responds to their needs.

The Segal method is an example of creating customised housing that does not require technical knowledge from the end-user if assisted by the architect's knowledge. The Segal method was created by the architect Walter Segal in the 1970s to allow self-builders to design their houses, becoming not only self-builders but also self-designers (Colaço & Mennan, 2021). It consisted of a modular timber-

framed set of panels designed for laypeople to combine them in almost any way to create customised houses in a simple way (Doe, 2018). Segal Close was the first project realised with the Segal method. The houses were built in the district of Lewisham, in London, where the self-builders were instructed about several aspects related to construction principles, logistics and legal concerns (Gierszon, 2014). Besides, the construction was made with "dry" light materials, reducing the construction difficulty and the need for construction equipment (Gierszon, 2014).

Another more contemporary example is the work of Studio Bark in the United Kingdom, particularly with the U-Build system. U-Build is a modular flat-pack timber system that allows non-experts to assemble building components with simple tools (Studio Bark, 2023a). Its application in the Nest House, where students and volunteers assembled the modules on site, demonstrates the potential of modular systems for participatory and accessible self-build housing (Studio Bark, 2023b). In addition, both the Segal method and the U-Build system allow the designs to be adaptable to changing needs, which is useful for inhabitants who want to change their houses in the future.

2.1.5.2 Flexibility and adaptability as key concepts for housing customisation

Flexibility and adaptability are key concepts in customising housing for a great amount of people. Yona Friedman was one of the pioneers of concepts such as flexibility, adaptability and empowering citizens to decide on the interior of their own houses (Lockard, 2017). Friedman was an architect who embraced the idea of a flexible architecture to respond to the needs of its future inhabitants. His best-known work is the Manifesto Mobile Architecture, in which he outlined 10 Principles of Spatial Urbanism, which propose a conceptual utopian city, Ville Spatiale (Figure 4), featuring modular, reconfigurable structures on top of existing cities (Barcio, 2017). This environment would be flexible, allowing inhabitants to define the configuration of their own dwellings. The structures would work as skeletons, with the interiors composed of multifunctional services and furniture modules for the inhabitants to customise (Lockard, 2017).

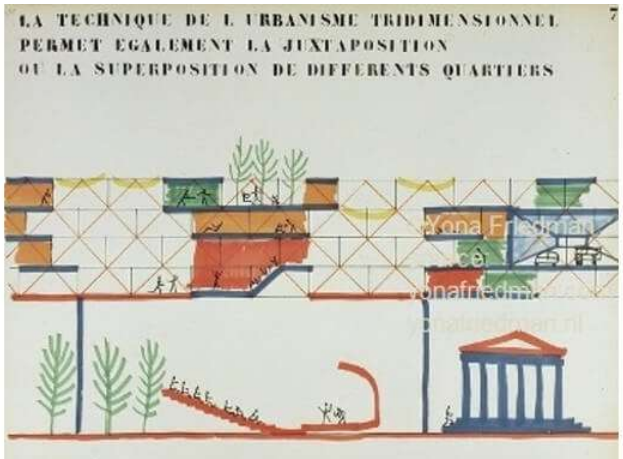


Figure 4_Yona Friedman's drawing from Ville Spatiale. Image retrieved from IDEELART (https://ideelart.com/pt/blogs/magazine/the-utopian-architecture-of-yona-friedman-reviewed-at-maxxi-rome)

Providing customised housing for a large number of people can be costly. Standard houses constructed after the Second World War used industrial methods based on efficiency and economy of production in quantity, focusing on affordable and low-cost production, resulting, however, in monotonous houses (Khalili-Araghi and Kolarevic, 2016). Mass customisation is a term initially coined by Stan Davis (1987) and later by Joseph Pine (1992), to the paradigm of providing customised products with the efficiency, affordability and speed of mass production (Khalili-Araghi and Kolarevic, 2016, 2018). According to Butt (2012) this approach combines the advantages of mass production with the flexibility of customisation. The author states that modularity is the key to mass customisation since standard modules can be combined to create customised products.

The level of customisation in housing varies depending on the degree of detail of that customisation, i.e. houses can be customised at a macro scale, such as structural materials, the exterior volume, and layout arrangement, or at a micro scale, such as interior finishing, colour, decoration and furniture arrangements (Jusan and Sulaiman, 2005; Yavari, Vale and Khajehzadeh, 2015).

Lampel and Mintzberg (1996) described five mass customising strategies, delineating the extent of user involvement in product development and delivery. The levels range from pure standardisation, with no user input, to pure customisation, involving full user-designer collaboration. Intermediate forms include segmented standardisation (adapted for buyer groups), customised standardisation (individual assembly from standard modules), and tailored customisation (user input during fabrication).

Another view of customisation levels is described by Noguchi and Hernàndez-Velasco (2005), who refer to the housing industry. The authors describe three levels of housing customisation: production, semi-custom, and custom design. Production design, prioritises economic efficiency through standardised construction, enabling buyers to view pre-built models. Semi-custom design offers a base model that buyers can adapt, while Custom design involves fully customised houses that, although with longer delivery times, are tailored to individual needs and preferences. A fourth level, mass custom design, is proposed by the authors, which combines standard components to enable diverse housing solutions while retaining the cost benefits of mass production. This method employs catalogues of functional, structural, and interior elements, allowing buyers to configure houses by selecting room types, layouts, and finishing materials (Noguchi and Hernàndez-Velasco, 2005). Accordingly, other authors such as Butt (2012) and Mohamed and Carbone (2022) state that the customisation can be done by choosing from different, architectural styles, room block modifications, layout arrangements, structural materials, interior and exterior finishings.

On the other hand, Khalili-Araghi and Kolarevic (2016) argue that catalogue-based housing design may limit user satisfaction due to restricted choices, while expanding options can reduce standardisation efficiency and overwhelm users. As a solution, they propose a flexible design space

enabling diverse housing configurations, alongside *dimensional customisation*, which adjusts the size of housing component. Khalili-Araghi and Kolarevic (2018) identify three customisation strategies: combining components, modifying product families, and using modular systems. These allow inhabitants to customise their houses through interior layout changes, modular reconfiguration, and dimensional adjustments (Khalili-Araghi and Kolarevic, 2018).

Modularity and flexibility, including dimensional customisation, have the potential to create variable architecture (Mohamed and Carbone, 2022). Such characteristics are essential to respond to a great variety of users' needs (Khalili-Araghi and Kolarevic, 2018). Furthermore, the original design should foresee the possibility of future customisation and have flexibility, adaptability and open-endedness to allow for house plan modification possibilities (Jusan and Sulaiman, 2005; Yavari, Vale and Khajehzadeh, 2015).

Habraken's pioneering work (Habraken, 1972) studies the concept of Open Building, which addresses an alternative for mass-housing customisation. John Habraken was a Dutch architect who argued that instead of deciding the future, the architect should create the conditions for buildings to adapt to various possibilities (Cuperus, 2002). His concept of Open Building involves creating a building that, without knowing who the end users will be, leaves its interior open to ensure the necessary flexibility to accommodate a wide range of possible preferences and needs. The Open Building concept identifies the relationship between the building's life cycle and the ever-changing needs of the end user. It follows principles of a financial nature, flexibility, and sustainability, with the intention of increasing the durability of the building (Kendall and Teicher, 2000). Flexibility is essential so that the building can adapt to the constant changes and diversity of the potential end users' needs.

In his book "Supports: an alternative to mass housing", Habraken (1972) defines three levels of decision-making corresponding to different design scales: Tissue (urban level), Support (base building level), and Infill (fit-out level). These levels represent different stakeholders' responsibilities, and the decisions made in each lower level do not compromise the upper level (Kendall and Teicher, 2000). The Tissue corresponds to the city's urban fabric in which buildings can be replaced without compromising the urban design. On the scale of the building, Habraken proposes that the interior of the building is independent of its shape, decoupling it into two entities with different life spans: the Support and the Infill (Cuperus, 2002). The support is the building's envelope, representing the framework for providing dwellings that can be defined and altered independently. The architect presents and designs the support's constraints. The infill is the interior arrangement defined by the inhabitants based on their preferences and needs, within the principles defined by the architect. The inhabitants can decide where to place the walls, kitchen and bathroom facilities, and choose the cabinets, appliances and finishings (Kendall and Teicher, 2000). The Infill comprises ephemeral systems that allow for changing the location of the infrastructures so that the interior can be easily reorganised

without affecting the base building. This increases the building's lifecycle while accommodating the inhabitants' changing needs.

Matura Infill System (Figure 5) developed by Habraken and Van Randen, is a construction system that enables buildings to have flexible interiors (Cuperus, 2002). The system aims to leave the walls free of any infrastructure, to ensure maximum freedom of spatial organisation. Matura is composed of two subsystems, namely, the Lower and Upper systems. The lower system consists of two main elements: (1) a 'Matrix Tile' and (2) a base profile channel. The matrix is placed on the floor and has grooves through which pipes and ducts pass. The base profile channels are profiles that fit the matrix grooves to support the partition walls, and conduct the electricity and communications cables (Cuperus, 2002). The upper system is composed of partitioning walls, doorframes, and kitchen and bathroom equipment (Kendall, 2015). Matura Infill System frees the walls of the infrastructure, making it possible to change its location so that the interior of the building can be easily reorganised. This system was later improved to enhance operability and compatibility, providing more flexibility and possibilities for partition walls, by introducing new features such as a 45-degree grid added to the matrix tile (Kendall, 2010; Yingying and Beisi, 2011).

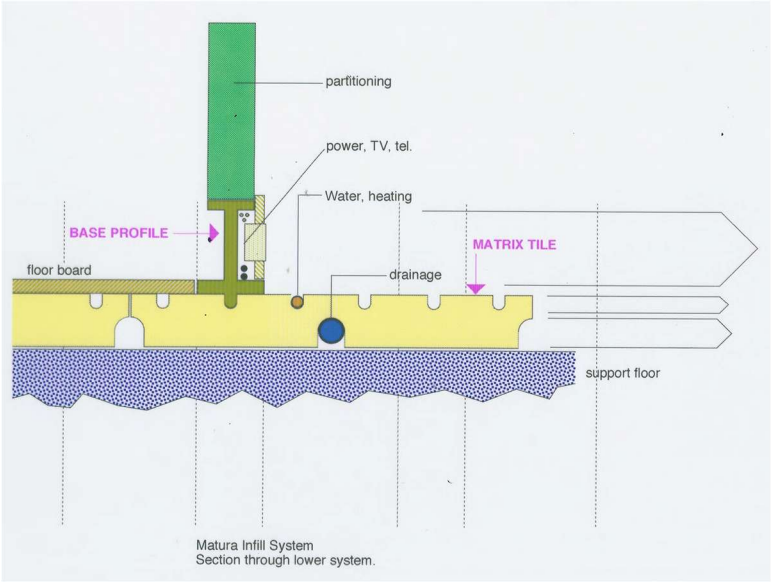


Figure 5_Matura Infill System: Section through the Lower system. Image retrieved from drstephenkendall.com (https://drstephenkendall.com/wp-content/uploads/2017/01/An-Oral-History-of-the-Matura-Infill-System-Development-copy.pdf)

According to Kendall (2006), the Open Building principles include the idea that the built environment is composed of different levels with different decision makers, admitting that the process is not only the domain of the architect and that the users must also make decisions. It also recognises that the needs of the inhabitants are constantly changing, as are the parts of the built environment that have different lifecycles. This concept has been applied in some buildings, such as the "Solids" in

the Netherlands, the “Plus Home” in Finland, “Free Plan Apartments” in Russia, and the Superlofts in the Netherlands.

According to Setien (2015), the “Solids” are long-lasting buildings designed to support various legal uses, such as housing, commercial, and cultural activities, through adaptable infrastructure. The Furore building (Figure 6), designed in Amsterdam in 2011, is an example of an award-winning Solid. Solids involve two construction phases. Initially, architects create the building envelope with open floor plans and raised flooring for flexible services. Subsequently, occupants customise the interior layout, finishes and equipment according to their needs and economic capabilities (Setien, 2015). While the developer is the building owner, tenants own the infill, which can be sold to future occupants (Kendall, 2013; Setien, 2015).

The SATO “Plus Home” concept is grounded in Open Building principles and offers fixed-price housing with three levels of resident choice. These range from selecting finishes and minor floorplan variations to full adaptability through Open Building technology (Kahri et al., 2006). The Pilot project, “Arabianranta” (Figure 7), was built in Helsinki in 2005 after winning a technology competition in 2001. Designed by Kahri&Co architects, Tocoman, and SATO, the project was awarded Finland’s best new building (Kendall, 2013; Setien, 2015). Its steel frame enabled rapid construction, while a degree of standardisation ensured cost control (Kahri et al., 2006). A shared platform integrated Building Information Modelling (BIM) software operated by the architects, and an online system, for inhabitants to customise layouts and materials with real-time pricing (Kahri et al., 2006). The façades vary according to residents’ interior choices (Malard et al., 2006).



Figure 6_The Solid Furore Building by Tony Fretton Architects. Image retrieved from ArchDaily (https://www.archdaily.com/207521/solid-11-tony-fretton-architects)



Figure 7_SATO Plus Home Pilot project “Arabianranta“ by Kahri&Co architects, Tocoman, and the SATO Corporation. Image retrieved from SATO website (https://www.sato.fi/en/rental-apartments/helsinki/arabianranta/kaj%20franckin%20katu%201/a25e711a-6f46-ea11-a812-000d3abaaceb)

The “Free plan” apartments in Russia, based on the Support/Infill system, allow occupants to customise interior layouts within a fixed structural framework. The Catamaran House (Figure 8), designed by Vladimir Plotkin in Moscow, exemplifies this approach, where infill decisions were

delegated to residents (Kendall & Kiseleva, 2013). The building comprises two parallel blocks, originally with balconies later converted into interior space, and flexible partitioning that enabled unit combination and reconfiguration. Integrated service conduits within the floor, along with lightweight partitions and a window-wall façade system, enabled adaptable interior layouts and façade modifications through panel replacement (Kendall & Kiseleva, 2013).

The "Superlofts", by Marc Koehler Architects (MKA) are modular, Open Building-based housing systems developed across the Netherlands. Designed for adaptability, they enable residents to customise layouts within a sustainable, prefabricated framework, aiming to extend building lifespan and reduce costs while creating a diverse mix of loft types that can easily adapt over time (Marc Koehler Architects, n.d.). Originating from a collaboration with housing cooperatives, the concept supports co-living communities through three design models (Place Maker, Home Maker, and Community Maker) tailored to site potential, unit diversity, and community making through shared spaces (Koehler, 2025; Marc Koehler Architects, n.d.). The "Casco" units (Figure 9) range from 35 to 200m² and allow flexible configurations (Koehler, 2025; Marc Koehler Architects, n.d.). The award-winning Houthavens projects exemplify this approach, with collaborative resident-led interior design and customisable façades (Koehler, 2025).

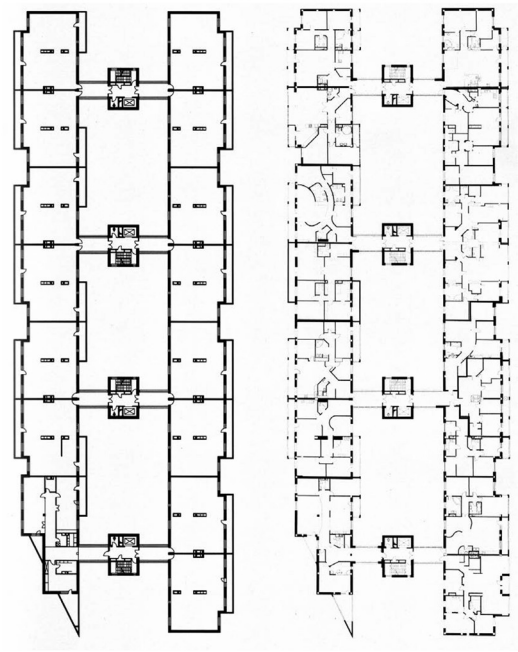


Figure 8_Catamaran House (a free-plan apartment building by Vladimir Plotkin in Moscow). The free-plan drawing given to the contractor (left) and a floorplan as originally built (right). Image retrieved from Kendall and Kiseleva (2013, p. 4)

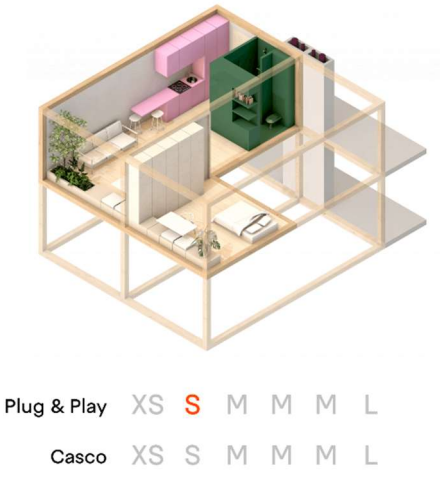


*Figure 9_*A *Superlofts* module type by Marc Koehler Architects. Studio loft with 45m2 (S) for a professional couple. Image retrieved from superlofts.co (https://superlofts.co/our-offer/)

2.1.5.3 Evolving shelter: Post-occupancy customisation for addressing changing needs over time

In developing countries, where poverty affects a significant portion of the population, inhabitants construct shelters, establishing priorities and improving them as their scarce resources allow. This leads to uncontrolled settlements, characterised by unsanitary conditions and a negative perception of these clusters in cities and suburbs (Greene & Rojas, 2008).

The Incremental Housing approach is, as promoted by Goethert (2016), an efficient strategy for supplying housing for the poorest. It consists of providing a serviced plot of land with a core housing unit containing basic facilities, such as a kitchen and a bathroom, as well as a multipurpose room that can evolve and be extended based on the financial capabilities of each family. According to Goethert (2010), although it is a slow and open-ended process, it provides secure ownership and flexibility in housing decisions to owners, who can control the expansion of their houses based on their needs and resources. Also, the housing modifications reflect the diversity of end-users and their home-making process, as the house enlargements are often the result of changing family structures and needs (Mora et al., 2019). Incremental housing is related to self-construction. However, strategies of urban growth are needed so that the neighbourhoods do not become the same as the illegal settlements, where houses grow individually rather than deriving from a joint effort for a cohesive environment (Mora et al., 2019).

Incremental housing strategies were extensively implemented in Latin American countries such as Chile, Mexico and Argentina (Mora et al., 2019), and the architecture office Elemental (Aravena & Iacobelli, 2016) extensively use this approach in their practice. The purpose of incremental housing is to combat poverty by delivering a liveable base core that can grow to achieve a middle-class standard (Arouca, 2018; Goethert, 2010). The base core is the starting point of a larger house for those who do not have the resources to support the initial costs (Neves and Amado, 2014). Aravena (2005) defend that the point of view is to see it not as a small unfinished house, but as a larger middle-class house, of which only a part is provided based on the resources available at the beginning.

Goethert (2016) discusses good practices, including aspects related to the starter housing unit, the use of local materials, the plot size and spatial arrangement of initial core units, and the need for developing multi-story incremental housing projects to achieve efficient land use, thereby allowing for proximity to cities and their infrastructures. Greene and Rojas (2008) identify three main phases of incremental housing construction: access to land for residential use, the construction of a basic habitable nucleus, and the incremental improvement of the dwelling.

A notable case of incremental housing is Elemental's intervention in Quinta Monroy, a neighbourhood in Iquique, Chile, which had been occupied by illegal settlements for more than 40 years. According to Greene and Rojas (2008), the efficient use of land is imperative for neighbourhood construction in plots near cities, especially in contexts with limited financial resources. This was a major

concern of Elemental office, led by Alejandro Aravena, when, under the "Vivienda Social Dinámica sin Deuda" (VSDsD), the Chilean government commissioned them to rehouse 100 low-income families. The state subsidy covered land acquisition, urban infrastructure, and housing construction (Aravena, 2004). As the subsidy was too low, the goal was to make the most efficient use of the land as possible, to maintain the families on that land, which was near the city and their opportunities and services.

The "parallel house" typology proposed by Elemental in response to the inefficiency presented by existing alternatives, enables horizontal and vertical expansion while maintaining spatial quality (Aravena, 2004; Arouca, 2018). Each lot contains two houses, one on the ground floor and the other on the upper floor, doubling land efficiency. Inspired by informal practices in Quinta Monroy, the design incorporates patio voids, that would be later occupied by the expansions (Figure 10), and communal spaces co-defined with residents, supporting social interaction and long-term value appreciation (Aravena, 2004, 2005).



Figure 10_Quinta Monroy by Elemental. Left: houses as delivered. Right: expansion made by the inhabitants. Images retrieved and adapted from Elemental's website (https://www.elementalchile.cl/works/iquique-violeta-parra-ex-quinta-monroy)

Complying with the second phase of incremental housing construction, the Elemental team opted to prioritise the construction of the service areas since they cannot be built without professional assistance (Arouca, 2018). According to Greene and Rojas (2008), this phase consists of providing a starter core with basic sanitary features, as these are the ones who need more assistance. The distribution of the remaining interior spaces was left to the dwellers' choice, enabling them to furnish and customise their houses according to their needs. Furthermore, the entire structure and external walls were built to ensure stability and quality in the construction, leaving it up to the residents to handle easily removable materials for future expansions. Neves and Amado (2014) emphasise the importance of utilising local materials to minimise construction costs in incremental housing projects given the scarce financial resources.

Regarding the incremental improvement of the houses, Greene and Rojas (2008) emphasise that incremental housing requires pre-defined designs, lists of materials and instructions for execution to

ensure quality. Neves and Amado (2014) highlight the importance of anticipating expansion conditions, noting that modularity enables evolution through aggregation, flexibility and division. Their project in Barrucho neighbourhood, an illegal settlement in Odivelas, Portugal, applied this approach using two modules: Module A allowed phased expansion and eventual subdivision, while Module B prioritised interior flexibility and division into independent units. Arouca (2018) argues that such frameworks support controlled growth without limiting residents' ability to personalise their houses, aiming for middle-class standards and accommodating diverse household needs.

Incremental Housing relies on end-user participation throughout design, construction, and post-occupancy adaptation as family needs demand and the resources allow. Neves and Amado (2014) argue that such involvement enhances appropriation and ensures housing meets residents' needs. Elemental facilitated this through workshops focused on technical guidance and collaborative decision-making (Arouca, 2018). These sessions enabled residents to interpret drawings, plan expansions, and understand design constraints. According to Arouca (2018), inhabitants were satisfied with the houses, and adhered to the extension plan, with deviations mainly occurring among few inhabitants who did not participate in the workshops.

Similarly, a study conducted by Mora et al. (2019) shows that limited resident participation in Chile's Incremental Housing Programme (1990–2002) led to unplanned modifications that compromised housing quality. The programme intended to include technical assistance and participatory design, however, these were seldom implemented (Mora et al., 2019). Consequently, residents altered service areas and expanded into backyards, affecting ventilation and lighting. According to Mora et al. (2019), these changes reflected evolving family structures and subsistence needs, such as increased privacy or storage for economic activities.

Another notable example of an incremental housing approach for housing customisation is the Malagueira housing complex by Siza Vieira in Évora, Portugal, which exemplifies both its potential and challenges. Developed collaboratively with the future inhabitants, the design of housing variants with different characteristics resulted from the lack of consensus among residents during the participatory sessions. The project introduced two courtyard house types and allowed for façade adjustments, reflecting user preferences (Mota, 2014a, 2018b). Despite international criticism (Mota, 2014a, 2014b, 2018), some residents praised the participatory process and design outcomes (A. L. Rodrigues, 2015). Siza proposed a catalogue of dwelling types, adaptable to the family evolution, governed by rules on size, height, and vernacular detailing (Mota, 2018b; A. L. Rodrigues, 2015). Over time, residents made both authorised and unauthorised modifications, including structural and aesthetic changes, such as placing stairs to the upper floor terrace, changing the dimensions of the windows and decorating surfaces (Mota, 2014b) (Figure 11).



Figure 11_Illegal changes made to a house in the Malagueira neighbourhood. Image retrieved from Eloy and Vermaas (2022, p. 401)

As demonstrated in the mentioned cases, the participation of end-users in the design process of their houses is paramount for the inhabitants to customise their houses with technical assistance. Such customisation ensures the design fits the inhabitants' needs and fosters their satisfaction and appropriation of it. Even if future changes or expansions are foreseen, such as in the incremental housing strategy, these changes need to be pre-established to ensure the quality of houses when customised by their occupants.

2.1.6 The role of Housing Cooperatives

Residents' satisfaction with the living environment is influenced by the ability to customise their domestic spaces but also by the sense of ownership. Empirical studies consistently demonstrate that individuals living in rented housing, including social housing, report lower levels of satisfaction compared to homeowners. Rohe, Zandt and McCarthy (2001), in their analysis of homeownership in the United States found that homeownership correlates with greater stability, attachment, and community engagement. Similarly, Elsinga and Hoekstra (2005), drawing on data from the European Community Household Panel, identified higher satisfaction among homeowners across European contexts, attributing this to enhanced security, autonomy, and financial advantages. Collectively, these findings suggest that homeownership fosters a stronger sense of appropriation and satisfaction with the living environment. Nonetheless, access to homeownership remains constrained for many, as speculative market dynamics continue to inflate property prices.

Known as the third sector, housing cooperatives offer an alternative housing solution that provides more affordable and suitable houses to their resident members compared to other housing access modalities. The literature defines housing cooperatives as legal associations that operate on a

membership basis, established to provide housing solutions to their members (Balmer & Gerber, 2017; Guity-Zapata & Stone, 2024). Residents acquire membership, which grants them the right to occupy a housing unit, share common spaces, and collectively own the entire building. Cooperative housing generally adheres to democratic principles, involving members equally in decisions regarding the management of the building (Balmer & Gerber, 2017). According to Richer (2010), housing cooperatives have a positive impact on the creation of more cohesive, participatory and democratic communities.

Affordable housing is often associated with housing cooperatives. Bredenoord (2017) argues that cooperative housing serves as an intermediary between Self-help and social housing, as it emerges from community movements. Housing cooperatives provide access to suitable housing for families who do not have other possibilities, such as access to social housing programmes. Indeed, a study conducted by Guity-Zapata and Stone (2024) explores the motivations of residents to live in housing cooperatives and cohousing in Hispanic American Countries (HAC) and Liberal Economy Countries (LEC) and reveals that economic and socio-political factors are the main reasons people choose to live in housing cooperatives and co-housing communities, especially in HAC.

2.1.6.1 The worldwide spread of Housing Cooperatives

According to Brandsen and Helderman (2012), housing cooperatives emerged in the 19th century and had two important moments: (1) the period of the industrial revolution, for rapid urbanisation, in which cooperatives were founded to create affordable housing for a large number of workers who moved to urban centers, and (2) the post-World War II period, in which cooperatives helped to rebuild bombed cities, gaining particular strength later in a period of instability and market globalisation, where social movements emerged in response to the trend of governments selling social housing properties to private investors seeking profit. These movements consisted of groups of residents purchasing housing estates, to ensure that their houses would not be sold (Brandsen & Helderman, 2012).

Although housing cooperatives emerged in Europe, particularly in Germany, Switzerland, and the Scandinavian countries (Balmer & Gerber, 2017; Brandsen & Helderman, 2012; Guity-Zapata & Stone, 2024), the phenomenon of housing cooperatives has spread worldwide, including countries as India, the United States, Honduras and Australia (Ganapati, 2010; Guity-Zapata et al., 2024). Latin America also has a strong cooperative culture, with Uruguay being a notable example. Uruguayan cooperatives emerged in the 1960s, driven by historical conditions such as the tradition of self-help and strong union movements, which led to the formation of federations and the pursuit of public policies that supported affordable housing (Richer, 2010).

Uruguay hosts two principal cooperative housing federations: FECOVI (Federación de Cooperativas de Vivienda), which serves middle-income groups through savings-based construction models, and FUCVAM (Federación Uruguaya de Cooperativas de Vivienda por Ayuda Mutua), which supports low-income families via mutual aid participation in construction processes (Bredenoord, 2017). The FUCVAM is the predominant model in Uruguay and gained international recognition in the late 1990s through support from We Effect, facilitating the transfer of cooperative practices to several Latin American countries. This dissemination earned the World Habitat Prize, in 2012 (Domínguez, 2017).

While Latin American cooperatives often target low-income populations, Balmer and Gerber (2017) note that the success of housing cooperatives in neoliberal contexts is their increasing catering to middle-income groups, supported by strong property rights and recognition as a "third way".

2.1.6.2 Types of property in housing cooperatives

Housing cooperatives encompass a range of models distinguished primarily by the type of property they provide. Individual Ownership Cooperatives allow residents to own and sell the housing units on the private market (Bredenoord, 2017; Richer, 2010). In Finance Cooperatives provide construction loans to members, while Building Cooperatives handle the construction process. Tenure Cooperatives retain ownership of the building, with members holding shares. Within this category, Limited Equity Cooperatives, limit speculation on resale of ownership shares to preserve affordability (Ellen et al., 2021; Ganapati, 2010).

Germany and the Scandinavian countries are leaders in cooperative housing, with dominant forms of housing provision being through homeownership and rental modalities. Brandsen and Helderman (2012) note that, while Scandinavian cooperatives are closer to the market due to the ability to sell units, Rental Housing Cooperatives, in which members pay a unit rent on a collectively owned building, are prominent in Germany, prioritising security tenure. The authors state that, in Germany, cooperative housing is often inherited, limiting external access and reinforcing long-term stability. Rental cooperatives also offer affordability through capped rents and are recognised for providing ontological security, defined by Guity-Zapata, Stone and Nygaard (2024) as secure occupancy and resident autonomy, contrasting with the insecurity typically associated with private and social renting.

Collective Ownership Cooperatives, involve joint acquisition of land and buildings, granting members occupancy rights without selling, ensuring that the houses remain outside the private market and remain affordable (Bredenoord, 2017; Richer, 2010). Uruguay is a leading example of this model, where cooperatives are grounded in principles of mutual aid, collective construction, and the conceptualisation of housing as a right rather than a commodity (Guity-Zapata & Stone, 2024).

2.1.6.3 Social bonds and democratic management

While economic motivations predominantly underpin the choice of cooperative housing in Hispanic American Countries, Guity-Zapata and Stone (2024) emphasise the significance of social aspects such as union and trust among residents, which distinguish cooperative living from state-provided housing models. The authors conceptualise the "house" as the physical structure, yet underscore the emotional transformation into a "home" through shared spatial experiences and interpersonal relationships (Guity-Zapata et al., 2024; Guity-Zapata & Stone, 2024). Housing cooperatives cultivate a sense of belonging, rooted in mutual support and community ties, which in turn encourage long-term residency and collective responsibility for building maintenance (Brandsen & Helderman, 2012). Collaborative activities, such as self-construction, urban agriculture, and recycling, facilitate skill sharing and knowledge exchange, particularly in smaller and newer cooperatives (Guity-Zapata & Stone, 2024). Nevertheless, Brandsen and Helderman (2012) observe that such activities are less prevalent in larger cooperatives, such as the traditional ones formed after the Second World War, where participation often relies on older residents. (Guity-Zapata & Stone, 2024)

Additionally, the efficacy of small-scale cooperatives is further attributed to their democratic governance and transparency. Residents actively engage in conflict resolution and management decisions, aligning individual and collective interests. Leadership is determined through voting, fostering accountability and inclusivity, in contrast to the detachment observed in larger, long-established cooperatives (Brandsen & Helderman, 2012). Richer (2010) reinforces the role of democratic participation in enhancing members' skills in collective decision-making and knowledge transfer, citing Uruguay as a paradigmatic case of civic empowerment and social cohesion.

2.1.6.4 Addressing inhabitants' needs

An important aspect of the success of cooperatives in Uruguay with self-construction, beyond cost reduction, was the fact that residents had the opportunity to make decisions about their own houses, which left them feeling proud of them (Bredenoord, 2017). The possibility to make decisions reflects residents' autonomy and control over their houses, which contributes to the feeling of home (Guity-Zapata et al., 2024). The residents' involvement enabled the houses to be adapted to their needs, which positively impacted the quality of the houses and the inhabitants' satisfaction (Guity-Zapata et al., 2024). According to Bredenoord (2017), the constructions received support from institutions and other NGOs, which provided guidance and technical assistance to ensure proper architectural quality. This, in turn, can be considered durable housing from both technical and social perspectives. Richer (2010) notes that by not allowing the sale of the houses, the collective property guarantees affordability and focuses on housing quality instead of property title.

A new model of housing cooperatives is emerging in several European countries, including The Netherlands, France, Spain, Germany and Austria (Brysch, 2018; Czischke et al., 2023). This new model emphasises collaboration where members are part of the decision-making process and actively participate in all phases, from land procurement to requirements definition, community-led design, construction, and post-occupancy management (Avilla-Royo et al., 2021). These cooperatives, exemplified by projects in Barcelona such as La Borda and Sostre Civic, integrate co-housing principles such as shared ownership, participatory decision-making, and collective spaces designed for communal activities. The houses have a base structure and can be customised similarly to the principles of open building and incremental housing approaches. Flexible layouts allow modular adaptation to the households' needs, with shared areas functioning as "common spaces for private uses" (Avilla-Royo et al., 2021). This approach challenges conventional housing norms and promotes sustainability, social cohesion, and inclusive living environments.

2.1.6.5 Institutional support

The support from external entities is indispensable for housing cooperatives. Ganapati (2010) states that institutional structures provide key support in respect of administrative, financial, and other issues. In the Uruguayan case, despite the construction being based on their savings (FECOVI) or labour (FUCVAM), the cooperatives received technical assistance from non-profit associations, which provided organisational and financial support and technical guidance for the project and construction (Bredenoord, 2017; Richer, 2010). This support was of primary importance for FUCVAM cooperatives, representing resistance to the lack of support from the state, and the neoliberal pressures favouring individual ownership (Domínguez, 2017).

European cooperatives, such as those in Germany and Switzerland, benefit from external financing but sustain themselves through rents and fees, as they target middle-income groups (Balmer & Gerber, 2017; Brandsen & Helderman, 2012). Ganapati (2010) advocates for 'embedded autonomy', where cooperatives retain self-management while engaging with supportive state structures. Sweden exemplifies this balance, while India and the US illustrate the limitations of either excessive dependence or complete autonomy (Ganapati, 2010).

In Spain, Barcelona's La Borda cooperative pioneered the surface right model, enabling long-term use of publicly-owned land . However, although La Borda received strong municipal support, other cooperatives of the Sostre Civic organisation faced stricter district-level regulation, requiring significant project adaptations (Avilla-Royo et al., 2021).

In summary, housing cooperatives play a crucial role in providing affordable housing for low- and middle-income populations. On the one hand, autoconstruction proved to be an important means of providing housing to the low-income groups, who are intensively involved in the construction to

reduce costs, while houses are constructed durably under professional supervision and meet inhabitants' expectations and needs (Bredenoord, 2017). On the other hand, in liberal economy countries, housing cooperatives play a crucial role in ensuring affordable housing through homeownership or rental security for low-to-middle income groups, who can afford some housing costs but not at regular market prices. Besides the economic aspects, cooperatives foster a feeling of "home" and a sense of belonging by creating social bonds, fostering democratic management and knowledge transfer through group activities in small-scale communities (Brandsen & Helderman, 2012; Guity-Zapata et al., 2024). In addition to democratic participation in management, the involvement of residents in the various phases of the process, including definition of requirements, design, and construction, is imperative for the customisation of the living environments and, consequently, appropriation. In spatial terms, the flexibility and modularity of the spaces allow the houses to be adapted to social diversity and the residents' changing needs over time (Avilla-Royo et al., 2021). Dominguez (2017) highlights the need for state support both at a financial level and in terms of creating laws that fulfill the right to housing, and recognising cooperatives as an effective means of affordable housing provision. In addition to financial support and land allocation, the support must also take the form of technical assistance, in the case of self-construction cooperatives (Domínguez, 2017). Avilla-Royo, Jacoby and Bilbao (2021) add that the traditional notions of household and dwelling limits are outdated and political support is needed to adjust regulations to new ways of living that allow for collaboration, collective use and more sustainable building performances.

2.1.6.6 Housing cooperatives in the Portuguese housing context

Portuguese housing cooperatives have experienced a fluctuating relationship with the state, shaped by persistent housing shortage and poor housing conditions since the 19th century. According to Sardinha and Carvalho (2007), government interventions have historically facilitated access to cooperative housing to middle and low-incomepopulations, primarily through enabling policies that support affordable housing.

In 1910 there was a dramatic situation with many people living in precarious conditions, especially due to the arrival of workers in large cities (Ildefonso et al., 2019). Over the years, government policies and housing development support programs have been created to help the poorest access decent housing. These measures included rent-controlled measures and social subsidies, social housing programs such as SAAL, and support for cooperative housing (Sardinha & Carvalho, 2007).

The development of cooperatives can be delineated into four distinct phases (Pedrosa, 2018; Sardinha & Carvalho, 2007). The initial phase began in 1894, with land acquisition initiatives in Lisbon (Pedrosa, 2018). In response to widespread housing precarity, Law No. 2,007 (1945)formally recognised cooperatives as viable economic alternative for housing provision. However, significant

expansion only occurred from the 1960s onwards (the second phase of Portuguese housing cooperatives), driven by middle class demand for affordable housing, even though with limited emphasis on collective solidarity (Pedrosa, 2018).

The third phase was catalysed by the 1974 revolution and the subsequent decree of August 6, which required the state support for cooperatives through land allocation, infrastructure, financing and technical assistance. This period saw the proliferation of affordable housing cooperatives (CHE), notably supported by the Housing Development Fund (FFH), with relevant examples in Lisbon, Setubal, Porto and Matosinhos (Pedrosa, 2018). Despite initial success, liberalisation policies and a shift in government priorities towards private homeownership led to a decline in support for cooperative housing (Sardinha & Carvalho, 2007). Cooperatives increasingly relied on self-financing and redirected their focus towards middle-income groups, marginalising lower-income beneficiaries.

The fourth phase is marked by the establishment of the National Institute for Housing (INH), in 1984, currently called the Institute for Housing and Urban Rehabilitation (IHRU), which regulated and supported housing cooperative activities. While cooperatives benefited from tax incentives and reduced construction rates, they were also subject to restrictive regulations. (Sardinha & Carvalho, 2007). According to Pedrosa (2018), the first decade of INH's activity is regarded as the peak period of cooperative housing, although activity decreased until the end of the century due to the withdrawal of subsidised loan schemes and rising land costs (Sardinha & Carvalho, 2007). There was a tendency for cooperatives to move into the middle class in response to high land values and the lack of financing for families with higher economic difficulties. This shift prompted cooperatives to adopt more individualised architectural designs and engage with the private housing market (Antunes, 2019; Pedrosa, 2018).

Sardinha and Carvalho (2007) conducted a study to understand whether cooperatives' social purpose (providing affordable housing to low-income people) and the social status of their members have changed over the years. Empirical data reveals a transformation in the socio-economic profile of cooperative members between 1974 and 2006.There has been a notable increase in income and education among members, and a tendency for further increase, with newer cooperatives comprising predominantly younger individuals (Sardinha & Carvalho, 2007). Nonetheless, affordability remains the principal motivation for cooperative membership, rather than communal values. The authors also report criticisms regarding housing quality, with newer residents expressing dissatisfaction with spatial dimensions and interior standards.

Pedrosa (2018) notes the need for cooperatives to adapt to a new reinvented housing context, since the existing heritage is sufficient and only needs rehabilitation and review of housing policies. Brysh (2018) criticises the Portuguese government for the economic and social need for affordable housing, also referring to the trends of demographic changes, such as the ageing of the population and

the emigration of young people due to the lack of conditions in Portugal. The author proposes co-housing cooperative models which, according to Coelho (2023), are being studied by housing cooperatives from FENACHE (National Federation of Economic Housing Cooperatives) for the creation of Co-housing solutions in Portugal adapted to the new demographic reality.

2.2 Participatory and collaborative processes

Community members and end-users, as the primary inhabitants of space, possess situated knowledge that meaningfully complements the technical expertise of architects. Despite growing recognition of the value of user involvement in architectural design, the potential for meaningful collaboration is frequently undermined by a lack of appropriate tools to support co-design practices.

This sub-chapter examines this gap, noting the distinction between participation and collaboration, and their influence on systemic barriers to co-design, including limited openness among professionals, low levels of user confidence or interest, and challenges in bridging disciplinary and experiential differences. The sub-chapter also addresses the discussion around the need to not only develop natural design tools, but also to redefine the architect's role from autonomous creator to facilitator of dialogue and shared authorship.

2.2.1 Definitions and levels of participation

Social participation in architectural design is a research topic that has been discussed since the 1960s by several authors, such as Yona Friedman (1958), Sherry Arnstein (1969), Carole Pateman (1970), John Habraken (1986), John Carp (1986), Fredrik Wulz (1986), Henry Sanoff (2000), among others. This concept has been practised across project typologies and scales, such as in public spaces, housing, and educational facilities. However, there is no single, definitive definition of participation, as it can be applied in various areas and encompasses multiple levels of action. Despite being widely discussed and applied, Davidson et al, (2007) note that community participation takes different forms in the literature, and even the terms 'community' and 'participation' are used in various contexts, which results in a non-clear definition of what community participation is. The authors state that this paradigm is used to describe approaches at a macro-scale, such as the involvement of community in the decisions of urban management, as well as an approach to community empowerment, decentralisation of responsibilities, using local knowledge, cost reduction in construction and as an informal strategy of survival, such as the Self-help approaches.

Authors such as Sherry Arnstein (1969) Carole Pateman (1970) and Fredrik Wulz (1986) clarify the concept of community participation by translating it into scales that categorise end-users' influence on decision-making. Arnstein and Pateman refer to participation as a political system of power

distribution involving citizens with different levels of authority. Wulz defines participation from the architecture's point of view as a method of incorporating end-user knowledge into the design process. According to this author, participation encompasses different levels of decision-making and interaction between the architect and the end-user.

Arnstein's seminal work, Ladder of Citizen Participation, conceptualises participation as a **spectrum ranging from the passive involvement to active citizen control in the decision-making process**. The model comprises eight hierarchical levels, categorised into non-participation degrees (*Manipulation* and *Therapy*), degrees of tokenism (*Informing, Consultation and Placation*) and degrees of citizen power (*Partnership, Delegated power*, and *Citizen control*) (Figure 12). Lower rungs represent superficial engagement, where authorities retain control while creating an illusion of inclusion. Mid-levels offer limited influence, often lacking transparency or meaningful responsiveness to citizen input. The upper rungs signify a redistribution of power, with citizens actively shaping decisions through formal mechanisms and collaborative governance. While Citizen Control denotes full autonomy over policies and programmes, Arnstein acknowledges that absolute control is rarely possible, even in small-scale initiatives.

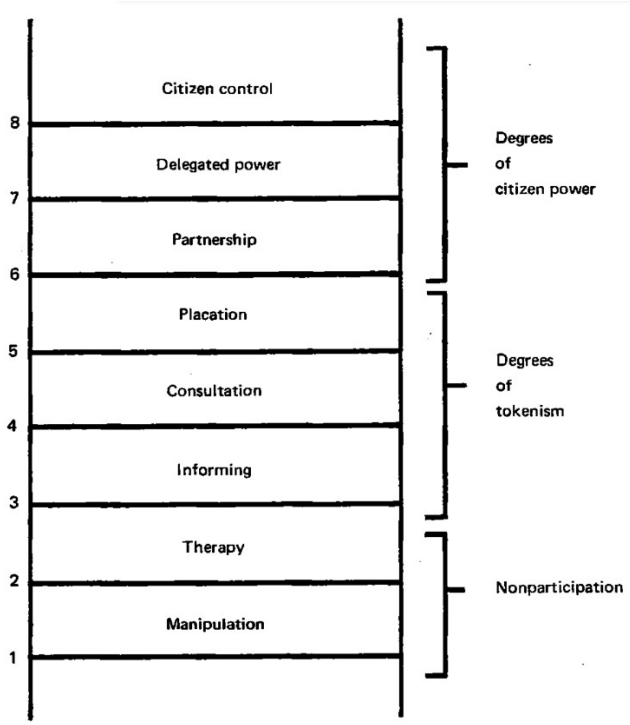


Figure 12_Arnstein's Ladder of Citizen Participation. Image retrieved from Arnstein (1969, p. 217).

Pateman (1970) also categorises participation into three levels (aligned with the three degrees on Arnstein's ladder): pseudo, partial, and total participation. According to the author, pseudo-participation is when users are included to legitimise pre-determined decisions, offering no real influence. Partial participation allows for limited engagement, such as consultation or discussion, yet

users do not have the ultimate authority. In contrast, total participation entails equitable involvement, where each participant has equal decision-making power. Pateman critiques traditional democratic models that assume citizens are passive and argues that full participation strengthens democracy, meaning that people feel their involvement has a meaningful impact.

Regarding the design process in architecture and urban planning, Wulz (1986) conceptualises participation as a **continuum of interaction between architect and end user**, ranging from passive to highly active involvement, with the following levels: *Representation, Questionnaire, Regionalism, Dialogue, Alternative, Co-decision* and *Self-decision*. The initial levels, *Representation* and *Questionnaire,* are characterised by minimal user influence, with architects interpreting or generalising user needs, often without direct engagement. *Regionalism* and *Dialogue* levels introduce a more contextual and interactive approach, incorporating local knowledge and user feedback, though decision-making remains with the architect. Participation becomes more active at the *Alternative* and *Co-decision* levels, in which end-users influence outcomes through individual choices or shared decision-making processes, although within frameworks still shaped by architects. The highest level, *Self-decision*, signifies full user control over design decisions, with architects serving primarily as technical consultants.

Additionally, several other authors, such as Fröst and Warren (2000), Kvan (2000), Achten (2002), De Koning, Crul and Wever (2016), Faliu *et al.* (2018), Stelzle and Noennig (2019) and Combrinck and Porter (2021), define participation in the design process at different levels, including participatory design, co-decision, co-creation, and co-design.

Relevant to the discussion is the **distinction between what it means to participate and to collaborate**, which gives rise to the distinction between participatory design and collaborative design. Architecture is collaborative by nature. The process of designing and implementing an architectural solution requires experts from various specialities, with different knowledge, to collaborate towards a common outcome. Participation, on the other hand, refers to the social component, in which end-users and other stakeholders are involved at some phase of the solution definition process. This does not mean, however, that a participatory process is necessarily collaborative, as it may not include non-experts in decision-making or proposal production. Nor does it mean that a collaborative process (such as a traditional architectural process) is participatory, as it may not involve end-users and other stakeholders at all.

Fröst and Warren (2000) define **participatory design** as a way to obtain information from future users to create proposals that meet their needs. This definition aligns with Wulz's Dialogue level of participation, in which the architect engages in dialogue with end users to collect feedback, without undervaluing their knowledge. According to Fröst and Warren (2000), a preliminary design project is shown to the inhabitants, who are invited to express their wishes and opinions to be considered by

the designer when defining the final design project. However, the architect reserves the right to make any appropriate changes, and the inhabitants do not have the power to decide whether the architect includes their suggestions or not.

Co-decision is the involvement of a group of stakeholders in decision-making, in which all participants have an equal influence on defining the result through voting or choosing certain aspects. On the other hand, Collaboration is the joint work, with the same goals, to achieve solutions that satisfy everyone involved (Kvan, 2000; Achten, 2002). Within collaborative frameworks, co-creation and co-design presuppose the active involvement of end users in proposing solutions.

Co-creation refers to collaboration in generating ideas prosing solutions through the exchange of knowledge and experiences (De Koning, Crul and Wever, 2016). End users develop their own ideas from the initial phases, rather than simply commenting on proposals prepared in advance by architects. These initial ideas are not a designed architectural project and therefore require an architecture professional to translate them into a design.

On the other hand, in architecture, **Collaborative design, or co-design**, refers to a collaboration in developing an architectural design from its initial phase. In this process, all parties involved have equal authority and actively contribute to the discussion of ideas and the creation of solutions. It is also assumed that, in co-design, they contribute to the proposal's design (Stelzle and Noennig, 2019). Co-design differs from co-creation in that, in the former, end users design the solution, whereas in the latter, they create and discuss design ideas that professionals later implement in an architectural design. In both cases, participation is active because the inhabitants influence both the decision-making and the creative aspects of idealising solutions. According to Combrinck and Porter (2021), co-design represents a step further in participatory processes, as it is an approach where, in addition to collaborating in the decision-making process with the same authority level, participants also contribute actively to produce the design proposal.

In short, referring to the design process, participation (including participatory design and co-decision) is related to the approval of the designers' solutions, while collaboration (including co-creation and co-design) is related to an active involvement in the design phases.

According to De Koning, Crul and Wever (2016), and Faliu et al. (2018), despite the distinction between participatory design and collaborative design, the authors state that a co-design process encompasses several phases that include the most passive levels of participation in the initial steps. These authors argue that in these processes, several steps are required, ranging from the provision of information to the joint definition of requirements and the development of design proposals between end users and the architect, who acts as the project coordinator.

According to these definitions, Table 2 systematises the levels of participation considered in this work. Non-participation and pseudo participation levels are not considered. The other levels are

conveyed into four categories (Participatory design, Co-decision, Co-creation and Co-design) and grouped according to their degree of participation or collaboration. Two parameters are considered: (1) at the political level, who is responsible for decision-making, and (2) at the architectural level, the involvement of participants in the definition and production of design solutions. The Activities column defines the activities performed by end users, which reflect the consequences of their influence on decision-making and the production of proposals.

Table 2_Levels of participation according to end-user involvement in decision-making and production of proposals.

Participation Level		**(1) Influence on decision-making**	**(2) Production of proposals**	**Activities made by end-users**
Participation	Participatory design	Architect	Architect	Define requirements and comment on proposals prepared in advance by architects.
	Co-decision	Architect + end-user	Architect	Make choices of certain aspects and vote on proposals prepared by architects.
Collaboration	Co-creation	Architect + end-user	Architect + end-user	Discuss and propose ideas that are later refined and designed by the architect.
	Co-design	Architect + end-user	End-user supported by the architect	Develop the design solutions.

Varying levels of end-users' involvement in housing design since the 60s have been exemplified by the work of the architects Ralph Erskine, Alvaro Siza Vieira and John Turner. In Erskine's Biker Wall (Newcastle, 1969-1975), the community participated through consultation sessions, allowing residents to express aspirations that informed the architects' design (Bandeirinha et al., 2022). In contrast, Siza Vieira's Punt en Komma housing complex (The Hague, 1984-1988) involved future inhabitants in spatial discussions using human-scale models, culminating in a collaboratively generated list of requirements for the architects to include in the design (Mota, 2019). Turner's work in Pampa de Cuevas, Lima, exemplifies a more active level of engagement, where the inhabitants not only decided on the design of their houses, but also constructed them, embodying self-managed development (Turner, 1967).

In educational contexts, participatory design was central in Christopher Alexander's work with the University of Oregon (Alexander et al., 1977), where the university community had a direct role in shaping the campus by contributing ideas and feedback through incremental, user-led interventions. Similarly in Kroll's La Mémé students' residence (Brussels, 1970s), medical students shaped the architectural proposals through collaborative hands-on workshops, influencing both spatial layout and aesthetic design of the building through modular, adaptable components (Gakhal, 2021; Patel, 2016).

Regarding public spaces and urban development, participatory budgeting exemplifies delegated power, enabling citizens to influence resource allocation. However, such processes require sustained political commitment, as shown by the first participatory budget, launched in Porto Alegre, Brazil, in 1989, where a decline in political support challenged its success. This is also evident in Hammarkullen, Sweden, where two initiatives –The Meeting Place (bottom-up) and The Patio (top-down) – demonstrated that neither community mobilisation nor institutional support alone is sufficient. The success of The Patio was contingent on the groundwork laid by The Meeting Place, that demonstrated the willingness and determination of residents to contribute to local development, underscoring the necessity of mutual commitment between governmental bodies and end-users for ensuring meaningful participatory outcomes (Stenberg, 2013).

All the examples mentioned in this sub-chapter represent different levels of community involvement. However, this idea of power transfer is criticised and raises questions about what is an acceptable way of producing architecture. As a result, participatory processes can be neglected, raising doubts about their legitimacy (Franco, 2015). Indeed, Erskine's Byker Wall, for example, was criticised for advocating a participatory process, while the architects' ideas were masked by the community involvement in consultation sessions (Franco, 2015). La Mémé was also a target of criticism. On the one hand, traditionalists criticised it for the chaotic and open-ended nature of the design, arguing that participation weakened architectural authority rather than enriching it (de Graaf, 2016). On the other hand, Kroll's approach was criticised for restricting individual freedom to limited possibilities of change, thus compromising the democratic aspect expected from the process (Patel, 2016). The next sub-chapter examines the benefits, challenges, and methods for effectively involving end-users in the design process through participatory and collaborative approaches.

2.2.2 Involving end users in participatory and collaborative processes

Several authors discuss the advantages of participatory design and how to enable end-user collaboration in the design process (Sanoff, 2008; De Koning, Crul and Wever, 2016; Münster et al., 2017; Faliu et al., 2018; Luck, 2018; Heijne and Meer, 2019; Stelzle and Noennig, 2019). These benefits, among others, include more responsive solutions to the end user's needs, as well as a sense of ownership, skill development, mutual learning, and community empowerment.

Effective management, development, and maintenance of cities depend on social participation in urban and architectural projects, as citizens (end-users) have direct experience of using these spaces. In fact, there is no one better than the local community to identify what is missing or what can be improved in a given place. Local authorities need this social knowledge for the solutions implemented to be accepted by citizens, who feel more empathy for the places if they have contributed to their creation (Sanoff, 2008). By having an active and participative role in the development of the spaces

they inhabit, literature shows that citizens acquire a higher feeling of identity, ownership, and pride towards their living surroundings (Marschall, 1998; Sanoff, 2000, 2008). As stated by Sanoff, "*People have more ownership for the program's success if they have had a part in creating it. They also hold a key element that only comes from their experience. Decision-makers need the voice of experience to line up with facts and figures produced by studies*" (Sanoff, 2008, p. 63). Also, Himaki et al. (2024) argue that while designers often create meaning through symbolic approaches, everyday users tend to derive meaning from their personal experiences, making it crucial to assess the needs of everyday users. Thus, social participation in urban and architectural development projects benefits both citizens, as they obtain solutions that respond to their daily needs, and authorities, since they guarantee that the solutions they implement are accepted and cheered.

Despite this, **social participation in architectural and urban design still lacks effective communication channels and user-friendly design tools to empower end-users in collaborating on the production of design proposals**. There are several issues involving citizens in the development of projects. Marschall (1998) and Sanoff (2008) list issues such as the difficulty of communication between professionals and citizens, the lack of representation of the population in public meetings, the lack of citizen attachment to places under consideration, and the lack of openness among professionals due to time-consuming processes and the lack of community knowledge and skills. The following sections examine these factors, which are considered challenges in participatory and collaborative processes, as well as the methods that can be used to overcome them.

2.2.2.1 Communication

Communication is crucial in architectural and urban planning participatory design not only because each person interprets things differently according to their knowledge, but also to coordinate tasks, exchange information, and make decisions. The confrontation of opinions feeds the discussion, exchange of experiences and points of view that lead to finding a common solution (Botero and Saad-Sulonen, 2010). However, the process should facilitate a **bi-directional discussion** among governmental stakeholders, designers, and end users, going beyond the traditional collection of requirements or provision of information about a project, as seen in lower levels of participation.

Several scholars highlight the limitations of traditional communication methods in participatory design processes. Kwiecinski, Markusiewicz and Pasternak (2017) note the spatial constraints of face-to-face discussions and advocate for alternative communication channels to engage **broader audience**. Münster et al. (2017) argue for a hybrid approach, combining the interpersonal benefits of in-person sessions with the extended reach and enabling potential of digital technologies. Digital technologies such as the internet facilitate collaboration, by enabling accessible, efficient information exchange that supports shared understanding and informed decision-making (Farias, 2019). Similarly, Chiu

(2002) emphasises the value of asynchronous communication and data storage in overcoming spatial and temporal barriers to participation.

Several digital platforms emerged to support public participation by facilitating **information exchange and community engagement**. Open data initiatives such as *Lisboa Aberta* (Open Lisbon) portal (Câmara Municipal de Lisboa, 2018) and *Lisboa Interativa* (LXi) (Interactive Lisbon) (Câmara Municipal de Lisboa, 2021a) provide regularly updated and georeferenced information on urban services and infrastructure, enabling citizens to access and reuse data produced by municipal authorities. Map-based tools as Waze (Waze Mobile, 2021) and *Na Minha Rua LX* (Câmara Municipal de Lisboa, 2021b) promote bidirectional communication, allowing users to report incidents or contribute with real-time traffic data, thereby informing urban management. Platforms such as Urban Mediator (Botero and Saad-Sulonen, 2008, 2010) and Web Map Media (Nuojua et al., 2008) further enhance citizen involvement by enabling to create and share location-based information and fostering dialogue between communities and planning authorities.

Independent of being traditional or digital, various authors such as (Sanoff, 2000; De Koning, Crul and Wever, 2016; Herda, 2017; Münster et al., 2017; Faliu et al., 2018; Stelzle and Noennig, 2019) state that the first step of collaborative processes is the sharing of information, which should be facilitated by the appropriate channels. Münster et al. (2017) provide an overview of different one-way and two-way communication channel possibilities, both physical and virtual, emphasising the importance of bidirectional communication for collaborative planning.

Effective collaboration in design requires, then, both the collection and dissemination of information, to and from potential end-users to define a design brief and even to prepare a collaborative session that adapts to the needs and skills of the participants. According to Herda (2017) methods such as field consultations, surveys, focus group discussions and in-depth interviews or thematic workshops can suit different target groups. Accordingly, Sanoff (2000) refers to surveys and questionnaires offer broad insights in community needs, preferences, and priorities, while qualitative methods enable a deeper understanding of specific concerns.

A collaborative process begins with awareness of the situation, encompassing physical, social, cultural, and economic aspects, and a clearly defined program with shared goals Sanoff (2000). As noted by De Koning, Crul and Wever (2016), Faliu et al. (2018), and Stelzle and Noennig (2019), a collaborative process unfolds in stages, which begin with information exchange, which is essential for meaningful engagement in subsequent design phases. Accordingly, providing accessible and relevant is critical to enabling informed citizen participation (Marschall, 1998).

Authors such as Treija, Bratuškins and Bondars (2017), Herda (2017), and Farias (2019) emphasise the effectiveness of **small-scale participatory processes**, noting that face-to-face discussions in limited groups foster interpersonal connections and empathy among community members. Small group

discussions enable everyone involved to share their opinions, enabling equitable contribution. Also, smaller-scale initiatives are recognised for enhancing citizens' understanding of local issues and contributing to large-scale transformation through the integration of multiple localised actions (Treija, Bratuškins and Bondars, 2017; Farias, 2019). .

Sanoff (2000) describes methods such as Participatory Action Research (PAR), which integrates research, planning, and action, through the active involvement of community members in every stage. Workshops and Charrettes support dialogue and shared ownership, with Workshops focusing on idea generation and decision-making, and Charrettes offering intensive, multi-day design sessions to collaboratively develop concrete design proposals. However, challenges such as stakeholder representation and managing divergent views can hinder these processes. As Marschall (1998) notes, conflicting meetings demotivate professionals. Therefore, skilled facilitation is essential to establish clear rules, mediate conflicts, and encourage mutual respect and understanding of others' needs to find consensus.

In collaborative design, **consensus** is understood not as a majority rule but as a process of mutual understanding grounded on principles of equality, dialogue, and social learning (Sanoff, 2000). It involves debate and the accommodation of diverse interests to reach solutions acceptable to all. Critics such as Miessen (2011) and Rescher (1995), argue that consensus can suppress disagreement and limit innovation, advocating instead for 'conflictual participation' and 'pluralism' which embrace disagreement as a productive force. However, Sanoff (2000, 2008) emphasises that consensus does not require uniformity but cooperation, emphasising group ownership of ideas to foster shared responsibility and collaboration, overcoming competitive barriers. The author outlines collaborative decision-making as a structured multi-stage process, supported by tools such as brainstorming, visioning, flowcharts, and evaluation matrices. Heijne and Meer (2019) prepared a practical guide designed to help facilitators in leading group creativity sessions. The book presents problem-solving techniques for co-creation sessions, covering both divergent (idea generation) and convergent (idea selection) phases, to guide participants through the process, from problem identification to solution implementation. This guide can help in selecting the appropriate method for discussion and consensus finding sessions in participatory and co-creation processes, according to specific parameters, such as the goals or skills of the participants.

2.2.2.2 Interest

One of the difficulties in carrying out meaningful participatory processes lies in the lack of interest from both professionals and end-users. Literature (Franco, 2015; Nuojua et al., 2008; Papa et al., 2017; Stenberg et al., 2017) shows that, on the one hand, consultation sessions are held, supposedly involving all stakeholders, when in fact they employ false participation by not including end users'

inputs. On the other hand, end users are demotivated by not seeing results from this 'participation', or do not participate due to a lack of attachment to the places under consideration. According to Combrinck & Porter (2021), involving end users in architectural participatory projects can either be empowering or disempowering, depending on the way they are treated and included. The author argues that designers should select adequate methods to facilitate collaboration so that end users do not feel discouraged.

End users may refuse to participate if they believe they will not be heard. An example of this situation is described by Papa et al. (2017), who state that after the transition period to democracy in the Balkan Region countries, people began to demand the right to participate in urban development, but the government only involved them in information sessions about what was going to be done. Technicians did not consult citizens about their needs and desires, assuming that experts knew more about societal needs than the citizens themselves. According to the authors, such a situation led the inhabitants not to trust the participatory processes. Therefore, they were not interested in participating in these sessions because their suggestions were never materialised. Another example is given by Nuojua et al. (2008), who report that citizens do not receive feedback on the outcome of discussions in which they participate, and city officials only partially incorporate their input into the design.

Stenberg et al. (2017) criticise the participatory processes launched by governments, as they see the community as a homogeneous group. The authors note that top-down participatory initiatives can be misleading because residents are given only the "tools that matter". There are hidden issues that are not brought up for debate because there is no openness to change them, thus creating a false sense of participation. However, the authors argue that consultation or information sessions (Arnstein's tokenism levels of participation) can encourage self-mobilisation.

In this line, for a more democratic process, Botero & Saad-Sulonen (2010) argue that authorities need to reconsider the role of citizens and provide the necessary tools for them to contribute actively to the design process. However, technicians tend to take control because they are not receptive to proposals produced by non-designers (Nuojua et al., 2008). In addition to considering participatory processes time-consuming (Mertens et al., 2023; Van Der Linden et al., 2018), **the 'star' attitude of architects hampers their willingness to let end users produce design proposals, assuming they do not have the necessary skills or knowledge** (Luck, 2018; Van Der Linden et al., 2018). Map-it, introduced by (Huybrechts et al., 2012), is an attempt to overcome this issue. It consists of a toolkit for architectural and urban design, developed to promote discussion and encourage designers to release control over the process. Participants are asked to set up map-based design projects with cards and assign stickers that trigger the confrontation of different opinions.

The lack of involvement in participatory projects is not only due to resistance on the part of professionals and authorities, but also to the **lack of motivation or interest on the part of end users** who face this lack of openness, or because they may not be aware of the importance of their participation. The term NIMBYism (short for "Not In My Back Yard") is referred by Sanoff (2000) as a common barrier to community participation in planning and design. The author argues that this attitude among end-users emerges when they oppose developments that they perceive as undesirable, often stemming from a lack of early and meaningful engagement. The lack of trust in government-initiated projects leads to resistance to change, especially when it directly affects their environment. On the other hand, when the project is aimed at a typology more directly linked to the user, as in the case of housing, the inhabitants who will be affected by the project are more interested in participating than when the object of study covers a broader area, as is the case with urban planning. Attachment awakens a sense of responsibility and belonging that motivates inhabitants to actively contribute to the decisions that shape their environment. As Sanoff stated "Citizens' attachment to places in their community can help to inspire action because people are motivated to protect and improve places that are meaningful to them" (Sanoff, 2008, p. 61). According to Sanoff (2000), besides the fulfilment of their needs, inhabitants also feel satisfied when they see that their decisions have, in fact, influenced the outcome. Moreover, having participated in the design also motivates its maintenance (Herda, 2017; Park et al., 2025).

The lack of end-user participation is not always due to disinterest, but rather a result of a **lack of awareness about the importance of their role** and the absence of invitation or empowerment. Users are frequently represented indirectly (e.g., by clients), and their voices are absent or abstracted (Van Der Linden et al., 2018). Sani et al. (2011) argue that many end users do not participate because they don't perceive themselves as decision-makers. Accordingly, Gryada et al. (2024) note that end users tend to be distanced from architects by intermediaries, which can weaken their sense of influence and importance. Therefore, even when participation is encouraged, they may not recognise their role or feel underqualified to contribute. Treija et al. (2017) highlight that the facilitator's communication should be encouraging and help participants clearly recognise their significance within the participatory sessions. Peerapun (2012) suggests that awareness-raising actions can counter negative attitudes, and the dissemination of previous participatory processes that led to satisfactory outcomes can encourage participation in new initiatives. Treija et al. (2017) also note that various activities and types of communication, such as open discussions and games, can contribute to attracting the interest of citizens

Several authors (Collazos *et al.*, 2007; Antle *et al.*, 2011; Balogh and Beszédes, 2013; Münster *et al.*, 2017) identify gamification as a powerful tool for fostering public engagement and collaborative problem-solving. Design games, such as those developed by Brandt and Messeter (2004), facilitate

multidisciplinary collaboration by simulating user-centred scenarios and structure idea generation through playful interaction. These games prioritise cooperation over competition and use tangible materials to support communication and design expression.

In digital environments, multiplayer games similarly promote collaborative learning, communication and task coordination (Balogh & Beszédes, 2013; Fröst, 2002; Fröst et al., 2001; Wendel et al., 2013). Examples such as Minecraft (Mojang, 2009), Chase the Cheese (Collazos et al., 2007) and Escape from Wilson Island (Wendel et al., 2013) illustrate how role-based interdependence fosters shared responsibility and goal achievement. These principles are applicable to participatory architectural design, where diverse expertise must converge through effective communication to define goals, resolve conflicts, and evaluate outcomes.

2.2.2.3 Co-design: collaboration in producing design proposals

Community empowerment, both in terms of influencing decision-making and developing skills, is one of the greatest and most frequently mentioned benefits of participatory and collaborative processes in architecture (Al-Kodmany, 2001; Davidson et al., 2007; Marschall, 1998; Ng et al., 2023; Sanoff, 2008; Stenberg, 2013; Till, 2005; Valladares, 2013). However, this empowerment only occurs when participants engage in activities and produce proposals in collaboration with each other and with architects. Knowledge exchange benefits both parties as architects contribute technical expertise, while inhabitants offer social insight and lived experience of the space (Loiseau et al., 2022). This mutual learning complements each other and fosters a richer understanding of the built environment and its needs. However, the **lack of technical knowledge and skills from non-designers** is assumed to be one of the main reasons architects do not involve the end-users in the design definition (Luck, 2018; Van Der Linden et al., 2018).

Till (2005) considers that most participatory processes provide false empowerment by misleading participants about their involvement, while decision-making remains in the power of other stakeholders. The author argues that architects dominate the process because they use technical language (that the participants do not understand) as a shield to present their ideas. Since the community, i.e. non-experts in architecture, lacks understanding of the architectural drawings presented, they cannot fully engage in the discussion. Till further advocates that new forms of communication, better adapted to the user's understanding, must be adopted to incorporate the user's knowledge into discussions and achieve what he calls transformative participation. The author argues that one of the most important issues in achieving genuine participation is the formulation of a shared language between users and designers. However, one of the obstacles to end-user collaboration in the design process is the **difficulty of finding such a common language** (Marschall, 1998). Indeed, if on the one hand, architects tend to use technical language, on the other hand, end-

users lack the ability to identify their needs and desires. Van Der Linden et al. (2018), state that there's an implicit assumption by the architects that users don't know what they want, or what they should have, which can discourage genuine participation. Khalili-Araghi & Kolarevic (2016), argue that not only do they not know what they want, but they are also often unable to convey it on paper. Till (2005) highlights the need for new ways of communication, in which the architect must be the 'negotiator of hope' and act as much more than a technical facilitator. Mertens et al. (2023) support this point of view and further argue for a shift in the architects' role and their training toward facilitating user participation in the professional practice. They also suggest **mutual learning from both parties to address common ground and bridge the gap between them**.

For future users to be able to express their desires and needs, they need to participate more actively in the design process, collaborating in the creation of ideas and the development of proposals. Faliu et al. (2018) argue that laypeople should be given the appropriate tools to help them express their ideas through the creation of proposals, otherwise, their participation will be limited to viewing and providing feedback on proposals made by designers. Supporting this, Marschall (1998) and Herda (2017) defend that community members can be instructed to help them develop their skills and architectural knowledge, through e.g. training workshops or courses. Madrazo & Cojo (2017) also emphasise the mutual learning within collaborative processes, underscoring the relevance of learning models such as Action Learning and Action Research in developing competencies among both designers and end-users in collaborative design contexts. Furthermore, Luck (2007) advocates for participatory action research as a means of facilitating mutual learning, emphasising its capacity to generate knowledge through active engagement and intervention in real-world contexts. According to Peerapun (2012), action research means in practice **'learn by doing'**, which term is rooted in the work of John Dewey (Dewey, 2008). According to Dewey, this approach suggests that **meaningful learning arises from direct experience**, followed by critical reflection. It aligns with experiential learning theory (Kolbe, 1984), which outlines a cycle of concrete experience, reflective observation, abstract conceptualisation, and active experimentation in authentic or simulated environments. These concepts emphasise experience as the foundation for constructing knowledge.

Serious games, originally inspired by military board games, emerged in the 60s and 70s in architecture and urban planning as pedagogical tools aimed at developing participants' cognitive and social skills rather than fostering competition (Keslacy, 2015). These games prioritised collaboration and simulation of real-world design challenges, encompassing social and economic dimensions. In participatory design contexts, serious games facilitate multidisciplinary interaction through the **use of pieces representing programmatic building elements**, such as kitchens, living rooms, bedrooms, or entire buildings, thereby promoting a shared language and enabling inclusive decision-making (Fröst, Johansson and Warrén, 2001; Fröst, 2002; Brandt and Messeter, 2004; Antle et al., 2011; Keslacy,

2015). Some architectural collaborative games were designed by architecture scholars, educators, and game enthusiasts, such as Richard Duke, Juan Pablo Bonta, Allan Feldt, Cedric Green, and Henry Sanoff, and were intended to enhance communication, negotiation, and conceptual understanding among both professionals and lay participants, rather than a scoring system (Keslacy, 2015). These games emphasised the architecture's interpretation as the foundation of design and, therefore, used strategies to create a common vocabulary. Retrieving Till's (2005) position, when a shared language is achieved, end users are capable of contributing to discussions and making informed decisions.

Brandt, Binder and Sanders (2013) state that "making activities" allow externalising thoughts and develop tacit knowledge, helping end-users to express their ideas. However, tools that help them give form to their wishes should be used. Participatory and collaborative design encompasses tools and techniques that involve designers and non-designers in creating new future scenarios. Sanders & Stappers (2014) state that while probes (e.g., questionnaires, surveys, and interviews) are used to gather information from end-users, toolkits (e.g., a set of physical artefacts) are used to **provide non-designers with means to generate the solutions themselves.** Sanoff (2000) advocates for using **visual techniques** such as drawings, models, and photo-based tools, to help participants visualise and critique design ideas, making abstract concepts more tangible.

Accordingly, Brandt, Binder and Sanders (2013) refer to toolkits to help create and visualise scenarios. To empower participation, different toolkits can be used, like paper mockups, 2D images, stickers, and 3D objects. These authors argue that **toolkits are adequate for non-designers since they provide users with graphic and tangible components to express their ideas**. They also argue that a good toolkit should be a group of finite tools that, when combined, can create numerous possibilities. Franke and Hader (2014) refer to toolkits as learning instruments that support decision-making for non-designers. The authors refer that these toolkits provide options for users who do not know what they want.

Faliu et al. (2018) believe that co-design requires **manipulating objects and three-dimensional visualisation** so that non-designers can better understand the space and design possibilities. Drawing, object manipulation, constructing models, and experimentation are important aspects of co-design activities. These authors facilitated participatory workshops for the design of a public park in Marseille, to support collective negotiation and design by non-designers. The participants used traditional tools such as pencils, pens, post-its, scissors, and tape to compose visual representations of park features and placed them on top of 2D maps. The authors observed that creativity was further enhanced through object manipulation. They argue that making tools enable access to latent and tacit knowledge, which often exceeds verbal or graphic expression, underscoring the importance of physical interaction in participatory design processes.

Faliu et al. (2018) further underscore the importance of 3D visualisation for supporting end-users in collaborative processes, noting its capacity to support dialogue by improving spatial understanding and the perception of design consequences in simulated environments. Similarly, Herda (2017b) advocates for the use of visual materials and physical models that non-professionals can easily understand. A notable precedent is the Spatial Development Laboratory (Ruimtelijk Ontwikkelings Laboratorium [ROL]) created and spread in the Netherlands during the 80s, which employed full-scale modular apartment models to provide end-users with a concrete spatial experience and overcome communication gaps between designers and end-users (Mota, 2019).

Building on these approaches, **digital technologies offer further potential to enhance spatial perception**. Farias (2019) acknowledges that, while Computer-Aided Design (CAD) tools have expanded architectural possibilities, they have simultaneously reinforced the notion that the architect remains the primary holder of the skills necessary to produce architecture. Nonetheless, the literature shows the transformative impact of digital technologies in participatory architectural processes. Immersive and interactive 3D visualisation (e.g., walkthrough 3D models) enable non-specialists to better understand spatial configurations and implications of design decisions (Al-Kodmany, 2001; Salter et al., 2009; Schroth et al., 2006). End-users must be able to understand what is presented, as they lack the skills to interpret technical drawings the same way as professionals (Münster et al., 2017). Although Al-Kodmany (2001) argues that traditional tools should be integrated with new technologies, the author also recognises that the computerised ones enable non-designers to make more informed decisions (not only, but also) for their realistic visualisation. Fröst (2002) argues that a clear visualisation supports equitable participation and informed decision-making. Kunze et al. (2011) also emphasise that combining simulation and design tools with multidisciplinary knowledge stimulates creativity and enhances the design possibilities, thus improving collaborative processes.

Digital technologies offer end-users natural 'making tools' to interact with a virtual environment and create design solutions (Faliu et al., 2018). To be effective, these tools should be easy to use so that users focus their attention on the task, rather than on how to use the tool. Touch-based interactions provide a **natural user experience**, by simulating familiar gestures, such as e.g., draggable digital elements to simulate placing stickers on maps, which are commonly used in traditional processes (Nuojua et al., 2008; Faliu et al., 2018). Besides, multi-touch digital tables enable multiple participants to engage in making activities simultaneously in presential workshops, as demonstrated by Antle et al. (2011) with Futura (Figure 13), a gamified, map-based platform that uses a multitouch digital table and fosters strategic thinking and environmental awareness in face-to-face design processes.

Extended realities (Kissel & Ramirez, 2024), including augmented and virtual reality, further support collaborative design by enabling in-situ visualisation and interaction through touch or by

interacting with visual markers that define the position of virtual objects (Figure 14). Kwiecinski et al. (2017) demonstrates this with an interactive augmented reality interface for co-designing public furniture, where physical object manipulation dynamically updates the design parameters in response to the user's actions, enhancing participation and strategic exploration. Virtual reality enhances participatory design by enabling immersive spatial exploration and interaction (Fröst & Warren, 2000). However, some authors (e.g., Fröst & Warren (2000), Conti et al. (2001), and Faliu et al. (2018)) argue that, beyond passive visualisation, its value lies in supporting object creation and editing, achieved by **selecting components from a predefined library and placing them through direct manipulation**. Such interactions within virtual environments may occur through conventional interfaces, or more immersive and natural interaction employing head-mounted displays (HMDs), gesture and voice recognition, and motion-tracking technologies. thereby making the experience more tangible and enhancing the sense of realism and embodiment (Gonzalez-Franco & Peck, 2018).



Figure 13_Futura game with users interacting with a multi-touch digital table. Image retrieved from Antle et al. (2013, p. 4)

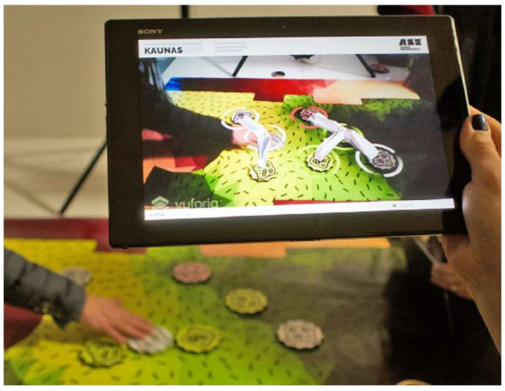


Figure 14_Interactive augmented reality interface showing the interaction with physical markers that define the virtual objects position. Image retrieved from Kwiecinski, Markusiewicz and Pasternak (2017, p. 751)

Virtual reality tools for architectural collaborative design are exemplified by Foresite Designer (Fröst, 2002; Fröst et al., 2001) and JCAD VR (Conti et al., 2001), which allow users to co-create and discuss architectural proposals, using 2D and 3D elements within immersive environments. Commercial platforms such as Prospect (IrisVR, 2019) and FuzorVR (Kalloc Tech Studios, 2021) extended these capabilities to distributed collaboration, through web-based interfaces enabling real-time interaction, annotation, and walkthroughs. In Prospect, immersive experiences using HMDs enable users to view avatars' gestures (Figure 15, left) and access floating menus with annotation and drawing tools (Figure 15, right), while FuzorVR supports real-time editing features within virtual environments linked with BIM-based models.

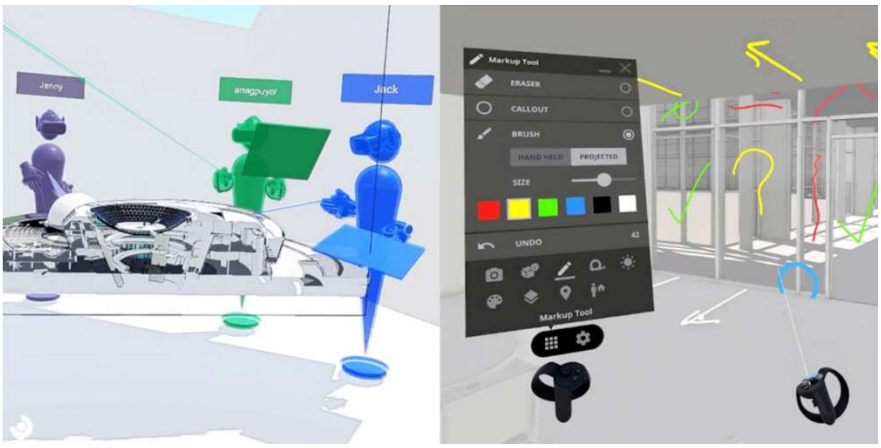


Figure 15_Prospect interface. Left: Meeting with participants' avatars pointing at a 3D model. Right: Immersive visualisation with a floating menu and annotations in the scene. Images retrieved from the IrisVR website (https://irisvr.com/prospect/)

Such technologies and types of human-computer interaction can be combined to create tools that take full advantage of the benefits of both physical and digital settings in participatory and collaborative processes. Faliu et al. (2018) developed an interactive virtual environment with different workspaces (Figure 16), merging immersive visualisation (HMD) and a tactile interaction (multitouch digital table), for face-to-face workshops. The U_CODE (Urban Collective Design Environment) project (European Union, 2019) proposes citizen-led urban development (Stelzle & Noennig, 2019) using a set of digital tools (Design Stormer, Smartphone Co-creation Tool, VR fox and Shape Table) across design phases, including web-based gamified brainstorming and mobile co-creation platforms. In focus groups, participants interact with proposals using VR Fox (Figure 17) and the Shape Table, facilitating collaborative refinement. Sentiment analysis further informs the process by capturing user responses to design outcomes (Jüngling, 2025).

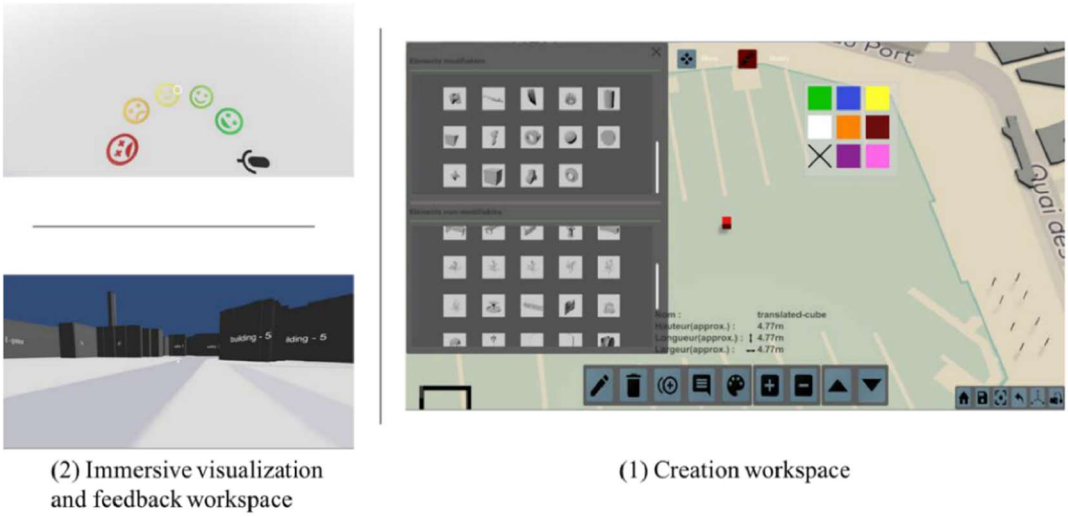


Figure 16_Different workspaces for design and visualisation. Left: Immersive visualisation and feedback workspace; Right: Creation workspace with a library of objects on the left and editing tools at the bottom. Image retrieved from Faliu et al., (2018, p. 9).



Figure 17_Preview of the U_CODE virtual reality tool intended for the VR Focus Groups. Image retrieved from Stelzle and Noennig (2019, p. 39).

In summary, digital technologies offer multiple benefits for the participation and collaboration of end-users in the design process. They enable reaching wider audiences than traditional participatory meetings, fostering bidirectional communication through enabling for informing the citizens and collecting their feedback and ideas about e.g. urban development projects (Botero & Saad-Sulonen, 2008, 2010; Farias, 2019; Kwiecinski et al., 2017; Münster et al., 2017; Nuojua et al., 2008). Digital tools also allow for asynchronous information exchange, such as common databases and shared files, and for remote synchronous discussions, overcoming geographical and temporal barriers (Chiu, 2002; IrisVR, 2019). Another advantage is their engaging potential, especially when used for collaborative gamified solutions (Collazos et al., 2007; Wendel et al., 2013). Interactive and immersive 3D visualisation enhances the end-users' understanding of space and design possibilities, bridging the gap between them and the professionals, and consequently improving participation (Al-Kodmany, 2001; Faliu et al., 2018; Fröst, 2002; Münster et al., 2017; Salter et al., 2009; Schroth et al., 2006). Digital technologies also have the capability of updating the design in real-time, allowing users to see the impact of their actions and make more informed decisions. Users can explore and develop design proposals through making activities using digital libraries and simple tools, which allow them to manipulate objects and digital environments, through natural interactions, such as those used in traditional workshops (Faliu et al., 2018; Fröst, 2002; Fröst et al., 2001; Kwiecinski et al., 2017; Nuojua et al., 2008; Stelzle & Noennig, 2019).

2.2.3 The role of the architect

2.2.3.1 Deconstructing the 'Star Architect' Paradigm

Historically, architectural practice has been shaped by a culture that privileges the figure of the 'star architect', a singular visionary whose creative genius dictates the design process. This model, grounded

in the ideals of individual authorship and professional control, positions the architect as the primary authority, often marginalising the input of other stakeholders (Combrinck & Porter, 2021; Luck, 2018).

Participatory design methodologies suggest that there are other ways of making architecture that embrace the power of the collective and of collaborative thinking. Such a paradigm challenges the fundamentally individualist nature of the architect, who offers resistance to democratic and inclusive approaches. Luck (2018) highlights that this resistance is not just a reluctance to change tools or methods, but it is more deeply tied to how architects see themselves and their role in the design process. For many, shifting toward collaboration with non-experts can feel like a threat to the traditional identity of the architect as the sole creator or visionary.

Picon (2010, 2016) traces the transition from the ideal of the isolated architectural genius to the contemporary collaborative, tech-driven design environments. According to the author, authorship is a distributed and, sometimes, ambiguous concept due to the collaborative nature of contemporary architecture, which involves large teams and shared processes. Furthermore, Carpo (2013) states that digital evolution opened architectural processes to interaction, collaboration, and community participation. Both authors (Carpo, 2013, 2017; Picon, 2010, 2016) argue that digital technologies have reshaped the notion of authorship in architecture, undermining the traditional role of the architect as sole creator.

Picon (2016) suggests that ownership is increasingly overtaking traditional notions of authorship. He argues that intelligent digital tools, such as e.g., parametric design software, have blurred the boundaries between author and tool, raising questions about who truly ’owns’ a design. On the other hand, Carpo (2013, 2017) notes that, while most digital fields embraced collaborative digital tools and participatory design, architecture largely resisted this shift. Instead of embracing communal authorship, architects often use digital tools to reinforce individual control. He explains that although parametric design systems allow for endless variations (see section 2.3.1), these are often curated or finalised by a single author, preserving traditional authorship even within a seemingly open system.

By shifting focus from individual authorship to a collective approach, participatory design calls for a redefinition of the architect’s role, not as an isolated creator, but as a mediator of knowledge, values, and aspirations. Habraken (1986) notes that everyone has their knowledge, refuting the paternalistic model of the architect's role. The author states that people must participate in the creation of their shelter and that “the future of the profession rests with those who seek to redefine its role” (Habraken, 1986, p. 143).

2.2.3.2 The Architect as Facilitator of Dialogue and Co-Creation

Central to participatory and collaborative approaches is the recognition of inhabitants as active co-authors of their environments. Their experiential knowledge, shaped by everyday interactions with

space, social relationships, and cultural practices, constitutes a vital resource for context-sensitive design. When given platforms to express their perspectives, communities can critically engage with spatial decisions and propose innovative solutions grounded in lived experiences. The architect's task, then, is to create conditions for this creativity to flourish. It is his task to cultivate dialogue, facilitate action, and provide tools that support self-expression. The architect enables inhabitants' contributions, nurturing a creative process where design outcomes are co-authored.

In participatory contexts, the architect assumes the role of facilitator, who enables dialogue among diverse actors, translates lay perspectives into spatial strategies, and supports the articulation of shared visions. This requires a significant expansion of the architect's skillset beyond traditional design expertise. Communication, negotiation, and empathetic listening become critical tools for engaging with divergent needs and expectations (Luck, 2007). The architect must also serve as a technical advisor, helping participants understand their needs and guiding them through the implications of design choices, construction constraints, and regulatory frameworks (Valladares, 2013). They must clearly communicate the strengths and weaknesses of a design to people who do not understand technical language (Treija et al., 2017). Also, rather than dictating outcomes, the architect provides technical support and helps inhabitants develop skills that empower them to contribute creatively and meaningfully (Marschall, 1998). This fosters a collaborative process in which design proposals emerge from a dynamic interplay between professional expertise and lived experience. Accordingly, Habraken (1986) believes that cities are living organisms, constantly changing, and the architects' mission is to feed the living environment to contribute to its spontaneous development. The author compares the architect's role to that of a gardener, who, understanding the essential conditions for growth, intervenes not to create the plants, but to enrich the soil and environment in which they can flourish autonomously and freely evolve.

The literature shows architects' efforts to embrace their new role in professional practice. Despite their historical distance, the SAR (Stichting Architecten Research), an architectural research foundation established in the 60s by a group of ten architects with the Dutch Union of Architects, and the Cuban Community Architect Program, created in the 90s, remain paradigmatic because they fundamentally redefined the architect's role from autonomous creator to facilitator of user intervention. Although SAR faced considerable difficulties, the initiative was nonetheless grounded in a deliberate attempt to reposition architects as enablers of participatory processes. Both models exemplify a shift toward participatory design, setting the foundation for contemporary practices that prioritise inclusivity, adaptability, and democratic engagement in the built environment.

Under the leadership of Habraken, SAR's activity was based on the Support-Infill concept, and its primary aim was to reform mass housing practices by introducing methods that allowed for greater user participation and flexibility in residential design (Carp, 1986). However, according to Carp (1986),

the implementation of this concept (see section 0) in some Dutch cities faced several challenges of a technical, legal and financial nature. Additionally, the author notes a major difficulty, namely, that the design teams were not prepared to reconsider their roles, choosing instead to maintain their traditional attitudes and approaches. On the other hand, the Cuban Community Architect Program, (Valladares, 2013) represents the 'enabling' role of architects in participatory and Self-help housing design. Through technical guidance, architects support residents in articulating their spatial needs and making informed decisions. In such participatory contexts, architects engage with families to gather information and invite them to contribute design ideas, which are then translated into three distinct architectural proposals shaped by the residents' requirements. These proposals serve as a foundation for discussion, during which the architect provides technical advice to help them understand the advantages and disadvantages of each proposal. The architect acts as a mediator, balancing the residents' requirements and regulatory and construction restrictions, while fostering an understanding of how their choices influence the outcome (Valladares, 2013).

2.2.3.3 Rethinking Architectural Education: Toward Participatory Practice

To sustain the shift in architectural practice, diverse authors defend that architectural education must undergo structural reform (Charalambous, 2017; Marschall, 1998; Zinoski & Marina, 2017). Evans (2017) argues that instead of the traditional curricula, often oriented to train 'star architects' to create notable buildings, future architects should be trained not only as designers, but as facilitators, educators, and cultural mediators, towards more socially oriented approaches, which designs reflect the local contexts. Charalambous (2017) further states that a gap exists between the architecture studio and the dynamics of a complex world, arguing that there is a need to **restructure architects' education** towards an enhanced connection with the communities they will serve. The author advocates for the collaboration between students and design studios in real-world projects, to nurture the learning process, and that students should deal with end-users, since participatory processes are fruitful for both developing knowledge and skills. Acknowledging that communication strategies are crucial in participatory processes, Luck (2007) highlights that the architects need to expand their skills beyond traditional design expertise. She further argues that the acquisition of conversational competencies in a participatory situation mostly occurs through practice and the observation of more experienced facilitators, reinforcing that the maturation of an architectural graduate occurs in real-world experience. Based on comparative observations in participatory design workshops led by experienced and non-experienced facilitators, Luck states that the communication of the facilitator affects the users' engagement in the design scheme.

Initiatives that incorporate participatory and collaborative principles are already emerging, such as university architectural programmes that integrate students into real-world community

collaborations, fostering experiential learning and civic engagement. Similarly, participatory initiatives such as Community Design Centres and workshops provide immersive environments where students engage directly with inhabitants and co-design spatial interventions. According to Sanoff (2000), Community Design Centres were established to provide architectural and planning services to underserved communities while also fostering participatory design practices. These centres, often associated with universities and nonprofit organisations, functioned as service providers and educational platforms and served as a bridge between professional designers and local residents, giving students and professionals hands-on experience in collaborative, socially responsive design.

Similarly, the OIKONET International Workshop held in 2014 at ISCTE (University Institute of Lisbon), in Lisbon, Portugal exemplified participatory pedagogical practice by engaging students in housing rehabilitation proposals through direct collaboration with local residents. Guided by a theoretical framework the workshop demonstrated the value of experiential, community-based learning within architectural education (Paio et al., 2017).

The literature highlights the academic efforts to offer students architectural training focused on community engagement across different countries. Examples include universities in Sweden (Stenberg et al., 2017), Puerto Rico and Chile (Rivera & Fernández, 2017), North Macedonia, Serbia and Albania (Zinoski & Marina, 2017), and Spain (Madrazo & Cojo, 2017), as detailed in the following paragraphs.

The University of Gothenburg, together with Chalmers University of Technology, founded a centre in Hammarkullen, Sweden, to develop higher education towards more context-driven programmes, while enabling inhabitants to become knowledge producers in academic work. The students' task in such programmes is to create design proposals for the area, based on dialogues with the inhabitants (Stenberg et al., 2017).

In South America, the School of Architecture of the University of Puerto Rico promotes academic programs that integrate community work through hands-on experiences in specific neighbourhoods. Students design participatory processes based on easy-to-use tools, such as collages, in which end-users create proposals, which are then translated into computer-generated visual representations to support shared understanding (Rivera & Fernández, 2017). Similarly, some architecture in Chile embeds participatory design in their curricula, with students conducting workshops that encourage end-users to generate ideas by placing stickers on maps informing the development of design proposals. The goal is to help students understand the value of working in close contact with the community, while also recognising the complexities and challenges that come with such collaboration.

Other examples from Europe include three universities from North Macedonia, Serbia and Albania (Zinoski & Marina, 2017). These three universities collaborated with the Ilinden Municipal Council in Skopje, North Macedonia, on the Living/Dwelling project, where students conducted workshops to investigate spatial use and social dynamics through interviews and questionnaires. They gathered

suggestions and presented development scenarios using maps for discussion with the community, fostering a shared learning experience among residents, students, and the local authorities Zinoski & Marina (2017).

In Spain, students from La Salle School of Architecture collaborated with the cohousing association Sostre Cívic during the seminar “Civic Housing”, to co-design the rehabilitation of a multi-family residential building intended for a housing cooperative in Barcelona (Madrazo & Cojo, 2017). Through participatory activities, such as mapping domestic preferences with post-its, residents played a central role in shaping the design brief (Madrazo & Cojo, 2017). This process enabled students to engage with residents’ lived experiences, which directly informed the architectural proposals.

Despite these initiatives, residents' input seems to be mostly tied to the definition of initial requirements and design brief, and with the discussion on proposals produced by the students. Accordingly, Combrinck & Porter (2021) show that there is still resistance to include participatory approaches in the academic training of architects. The authors developed a series of design workshops within the framework of a master's programme, and found that the critique panel showed resistance to participation beyond the sketch design phase (concept, brief, ideation). Their position reflects a broader tension between conventional architectural pedagogy and socially responsive design. More efforts need to be made to train undergraduate architectural students in their facilitation skills, to enhance the collaboration of end users in the design of proposals.

2.3 Digital technologies in Collaborative Housing Customisation

The evolution of digital technologies, from CAD tools to automated tools such as generative design systems and AI-based design, has expanded the capacity to produce diverse housing layouts responsive to user needs. However, these tools are often targeted only at designers, whereas co-design processes require user-friendly interfaces to support end-user involvement in the design process.

This chapter explores the potential of using digital technologies in co-design processes. However, while some initiatives aim to develop tools for the design of customised housing, the literature shows no evidence of interfaces explicitly conceived for end users or developed with their involvement. This gap highlights the need for user-centred methodologies, where iterative testing with inhabitants supports the creation of accessible platforms for housing co-design.

2.3.1 The impact of evolving technologies on the generation of architectural solutions

Digital technologies have brought new tools for producing architectural projects more efficiently and collaboratively. Technologies such **as Computer-Aided Design (CAD)** and Computer-Aided

Manufacturing (CAM) have had a remarkable impact on architecture by transforming the design process and the way buildings are conceived and constructed. CAD enhanced traditional hand-drawing techniques and opened up the possibilities of architectural solutions, enabling architects to create complex 2D and 3D models and iterate rapidly and efficiently (Knight, 2024). Furthermore, by enabling architects to simulate spatial configurations in three dimensions, design proposals can be understandably communicated to clients, since CAD-rendered 3D models facilitate comprehension by offering multiple perspectives, thereby minimising the need for prior architectural expertise from the viewer (Nejadriahi & Arab, 2017). CAD tools also enable the extraction of information from a completed model quickly and easily, particularly when using Building Information Modelling (BIM) technology, which embeds detailed information into each building component. Similarly, CAM extended this transformation into fabrication, allowing digital models to be directly translated into physical components through automated processes. Carpo (2017) notes the digital era's ability to transform the production of standardised building components into unique, variable forms at scale. Accordingly, Mohamed & Carbone (2022) argue that, together, CAD and CAM bridged the gap between design and production, fostering mass-customisation, therefore enhancing the variability in production of building components to adapt designs in response to end-users' individual requirements in a cost-effective manner.

Simultaneously, Carpo (2017) highlights how digital tools foster collaborative authorship through the rise of open-source platforms and **collaborative design environments**. These tools allow multiple participants to access the same information through cloud-based data storage and synchronised files, e.g., shared BIM 3D models, allowing them to work on the same project. These technologies overcome spatial and temporal barriers, enhancing collaboration between participants who do not share the same physical space. The work is coordinated with blocking mechanisms, conflict identification and resolution (Achten, 2002).

Carpo (2017) argues that while the first digital turn focused on using computers as tools for improving efficiency and enabling mass customisation, the second digital turn, on the other hand, is about using digital tools as thinking machines. The author argues that algorithmic design introduces a new paradigm where form is no longer drawn manually but generated computationally, and that the architect becomes a designer of systems, setting up frameworks that can produce infinite variations.

Generative design is a computational process in which the computer generates multiple design solutions based on parameters or predefined rules. This process allows for the exploration of solutions within a wide range of design options in a short amount of time (Tomić et al., 2023). Generative design systems can be supported by, e.g., parametric design or shape grammars.

Parametric design is an algorithm-based method in which the parameters' changeable values allow for the manipulation of the geometry and the exploration of solutions within a wide range of

possibilities, to optimise the form and increase the efficiency of the design analysis (Dino, 2012a). Parametric design, combined with BIM modelling, has been used by several offices, as Populous on the design of Aviva stadium in Dublin (Dino, 2012b; Feist, 2016a), Ateliers Jean Nouvel on Louvre museum of Abu Dhabi (Feist, 2016b) and Zaha Hadid Architects with the parametric BIM generation of City of Dreams casino in Macau (Van Der Heijden et al., 2015). Other well-known groups follow parametric design methodologies and have developed design systems based on parametric issues, e.g., Ghery Technologies developed the Digital Project, a parametric modelling system that enables the design of complex geometries and sculptural form (Feist, 2016b). Also, the Dutch architecture office MVRDV has collaborated with The Why Factory to develop a set of design tools that enable the creation of designs controlled by parameters, such as the Functionmixer, Citymaker and Villagemaker, that facilitate collaborative urban design processes (Zuidgeest et al., 2013). These architectural offices have sustained their engagement with parametric and computational design beyond the examples mentioned, as exemplified by MVRDV's project Chengdu Sky Valley (MVRDV, 2020), which integrates data-driven strategies. This ongoing commitment is institutionalised through MVRDV NEXT, the firm's internal taskforce focused on advancing computational workflows and technological innovation in architectural practice (MVRDV, no date). Khalili-Araghi & Kolarevic (2016) show that digital tools that combine parametric design with BIM allow for establishing limits that **ensure the viability and validation of solutions, while still maintaining the freedom to customise**. The authors propose a dimensional customisation system based on parametric BIM, where different dimensional parameters can be applied to adapt the design to users' preferences. Such a system enables the exploration within a flexible solution space with an infinite number of dimensional variations.

Shape grammars, introduced by (Stiny & Gips, 1972), are generative systems that create designs, or composed shapes, by recursively applying shape rules (defined by shapes and spatial relations) to an initial shape, allowing for the exploration of large solution spaces depending on the rules' possibilities. Shape grammars have been applied to several fields as fine arts, decorative arts, product design and architecture, and focus on several properties of the shapes as dimensional space (2D, 3D, etc), colour, and function assignments (Garcia, 2017). There are also different purposes for their use: they can be used as analytical tools, to generate new designs and also to generate transformations. A foundational architectural example is the Palladian Grammar developed by Stiny & Mitchell (1978), the first shape grammar written for the architectural field, which was capable of generating the original designs of Palladian villas and creating hypothetical new ones in the Palladian style. Their work demonstrates how housing morphology can be encoded through rule-based systems. By translating Palladio's principles of symmetry, spatial hierarchy, proportion and grid use into a parametric grammar, they show that the organisation of the villas emerges from rules governing spatial types, adjacencies and dimensions (Stiny & Mitchell, 1978). This makes the

generative logic of a historical domestic language explicit and reproducible. Duarte's work on Álvaro Siza's houses at the Quinta da Malagueira extends this approach to a contemporary housing system. His discursive grammar formalises the morphology of Siza's patio houses by structuring the plot into functional zones and embedding regulatory constraints (Duarte, 2001, 2005a). The system enables controlled variation and user customization while preserving a coherent morphological identity, demonstrating how rule-based methods can support mass customisation within a consistent architectural language. Other more recent example of shape grammars developed for housing layout generation in a specific style is the work of Eloy (2012) that developed a grammar to generate customised housing design transformations, within a specific style and based on the preferences and needs of the end-users.

The potential of grammar-based design systems has been empirically tested. Eloy et al. (2017) conducted an experiment to determine whether designs created by shape grammars are similar in design quality to those created by professional architects. The experiment compared the quality of design solutions for refurbishing apartments generated by six architects and by the Rabo de Bacalhau (RdB) shape grammar (Eloy, 2012). The results showed that the grammar had a distinctly higher performance than the architects' designs. The assessment was made by a panel of architectural experts and considered preliminary designs created by architects and the design generated by the grammar. The authors argue that shape grammars are developed based on knowledge of an architectural context or language, thus incorporating it into their rules, which human architects may not fully apply. Vermaas & Eloy (2021) also show that shape grammars design systems realise customisation and inhabitants' autonomy values in the design of new and refurbished apartments, while preserving design quality and structural safety, as they **incorporate architectural knowledge and construction regulations**. The authors also argue that the role of the architect will change from the author of an individual design to that of a creator of design systems, which embeds their expertise in grammar rules that guide inhabitant-led customisation, thus reflecting a more collaborative and flexible model of architectural practice.

These cases show that grammar-based methods operate as rule-driven housing systems in which architectural knowledge is embedded in explicit operations. They demonstrate that housing morphology can be systematically defined and varied within a coherent framework, supporting the development of customisable housing systems that preserve architectural coherence and performance. This shift suggests a broader transformation in architectural practice from the architect as the author of individual designs to the creator of design systems that enable informed, inhabitant-led customisation.

Besides parametric and shape grammar approaches, Mohamed & Carbone (2022) argue that tools supported by advanced technologies such as algorithmic design and artificial intelligence (AI) can be

considered an extension to parametric CAD/BIM tools. The authors also state that the growing role of generative design tools in architecture implies new possibilities for customisation in the housing industry. The **automatic floorplan generation is increasingly driven by AI and algorithmic design**, which offers faster, more flexible, and scalable solutions. Two categories of techniques can be used, namely **procedural and deep generative learning approaches**. According to Yenew & Assefa (2024) procedural methods, such as parametric design and shape grammars, use predefined rules and algorithms to generate layouts and are often based on geometric constraints and adjacency. On the other hand, deep generative models use machine learning to learn patterns from existing floorplans and reproduce them. Such technologies also allow for refining the generated floorplans for achieving optimal solutions best suited to the users' requirements. This refinement can be made manually, supported by algorithms or automatically during the generation process.

Finch (Finch, 2022) is a generative design platform that helps architects optimise building designs using AI, graph technology, and advanced algorithms. It automatically generates floor plans and provides real-time performance data to guide design decisions. Finch workflow starts by uploading a previously modelled building volumetry in which the user can arrange general characteristics such as the number of floors and their heights. The interior is defined by setting the circulation, the distribution and the dimension of each area, which are calculated by type (e.g. residential, commercial and others). Within the units, an AI-based feature presents suggestions of apartment layouts based on requirements selected by the user and, when a layout is chosen, the rate of compliance with certain aspects, such as daylight score, is presented. The user can adjust the design by, e.g., changing the position of doors or walls, while the system adjusts the layout according to the user's input and maintains regulatory constraints compliance. According to Jesper Wallgren, architect and founder of Finch, the system has two types of intelligence: rule-based and AI (J. T. Franco, 2019). As he explains, the AI part is responsible for the generation of layout suggestions, based on the analysis of existing dwelling floorplans. The rule-based technology uses an algorithm to support the adjustments made by the user's input. The architect notes that the generated suggestions are not intended to be the final design, but rather a starting point for an architect to work on and customise.

Another intelligent tool for the **automated generation and refinement of dwelling floorplans** is the work of E. Rodrigues et al. (2013a), who introduced the Evolutionary Program for the Space Allocation Problem (EPSAP), a hybrid algorithm that simulates natural selection by evolving a population of layouts according to user-defined constraints, such as, e.g., room sizes, connectivity and opening positions, and locally optimises each solution through adaptive geometric transformations. Performance evaluations demonstrated the tool's capacity to rapidly generate diverse layouts that respect all constraints and quickly evolve them into high-quality solutions, suitable for early design stages, that help architects explore layout possibilities before committing to detailed drawings (E.

Rodrigues et al., 2013b). However, the volume of solutions produced by generative systems can overwhelm decision-making. Sousa-Rodrigues et al. (2015) proposed the automatic clustering of floorplans based on shared features, reflecting the similarity criteria used by design professionals and students. Their findings highlight the dominance of interior configurations of spaces over the overall shape and external openings in similarity judgements, suggesting that such insights can inform machine learning algorithms for the clustering of floorplans resulting from generative design methods. Further research by E. Rodrigues et al. (2017) also underscores the practical applications of automated classification in supporting design selection, guiding generation processes, and organising data for stakeholder engagement.

Such applications can support the matching of architectural floorplans to distinct user categories by analysing preference-driven criteria, such as the work of (Mohamed & Carbone, 2022), who defined a framework based on generative design which creates housing designs based on parameters corresponding to end-users' characteristics. Within the proposed configuration system, a search engine algorithmically matches end-user profiles with pre-generated housing layouts that can be further customised. Besides the selection of materials and finishes, the decision-making is extended to the spatial adaptation of individual room blocks. This allows the initial layout to be reconfigured into a spatial arrangement more closely aligned with the user's needs and preferences.

2.3.2 Computational systems for housing customisation and co-design

Digital tools play a significant role in housing customisation, as they **enable the efficient design of various possibilities**. In addition, generative design tools can help co-design processes. According to Van Der Linden et al. (2018) and Mertens et al. (2023), architects find participatory processes time-consuming, which is a drawback in conducting participatory and collaborative processes. Authors such as Khalili-Araghi & Kolarevic (2018) and Kwieciński & Słyk (2023) recognise the fact that traditional processes with manual participatory and co-design techniques are costly and time-consuming, both for their analogic nature and for validating the designs produced by laypeople. According to Kwieciński & Słyk (2023), in traditional participatory processes, viability is ensured by the architect, however, the need to update the design to accommodate the expectations expressed by the participants turns the process time-consuming and limits the number of iterations. Recognising the importance of end-user involvement, the authors highlight the need to address other ways of validating multiple design solutions created by the end-users, arguing that generative design systems are necessary for this task since such systems are **based on pre-validated design rules**. Also, Khalili-Araghi & Kolarevic (2018) argue that the use of computational tools and technologies such as generative design allows for increasing the number of iterations and expanding the range of solutions, thus responding to the

diversity of users' needs without sacrificing the validity of the solutions. In this way, it is possible to **overcome the time and scale barriers common in traditional participatory processes.**

In the literature, one can find several computational systems specially developed for the design of customised housing and for involving end-users in the decision-making. Different techniques to generate housing designs have been developed and evolved over time. Despite the technology used**, this work focuses on its application to tools whose interfaces aim at helping inhabitants identify and represent their desires and needs when designing their future houses**. Pioneering approaches to housing customisation by inhabitants include the flatwritter, proposed by Yona Friedman, and a microcomputer program developed by the SAR group.

Friedman advocated for end-users to decide on their own housing, making them understand the implications of their choices. To this end, he proposed the Flatwriter in 1971, a writing machine enabling inhabitants to compose apartments through sequential decisions within a framework of prefabricated elements and service units, while the system would inform the consequences of their decisions (Friedman, 1971). The Flatwritter would incorporate millions of potential floorplans that could be achieved through a sequence of choices regarding the housing layout using a keyboard, which would be inserted into a shared structural skeleton, with warnings about conflicting choices. **The architect would have the new task of determining the possibilities of choices** for a great number of inhabitants. Although never executed, the literature shows that Friedman's ideas, once considered utopian, are now feasible through parametric and generative design.

In the late 70s and early 80s, the SAR office produced a microcomputer program to support user consultations to empower inhabitants in shaping their living spaces while maintaining architectural feasibility (Bosma et al., 2000). Grounded in Habraken's Support-Infill concept, the tool allowed to configure layouts by selecting and arranging the infill from a catalogue with price information, and visualising their integration within the fixed support structure (You, 1998). The rule-based system ensured that user-generated designs were structurally viable and met regulatory constraints. This example showed that **digital technologies can mediate between professional expertise and user participation**.

Different **intelligent tools** are now available for guaranteeing architecture compliance with regulations based on cutting-edge technologies, e.g. machine learning, genetic algorithms and artificial intelligence. Examples of such tools are TestFit (TestFit Inc, 2017) and Archistar (Archistar Pty Ltd, 2017), AI-based systems designed for the optimisation of site plots and assessing their feasibility in a detailed plot analysis (Mitrana, 2021). Other tools such as Prism (Mayor of London et al., 2020), Finch (Finch, 2022) and Architechtures (SmartScapes Studio SL, 2019) were developed to generate different solutions for buildings that comply with construction regulations. With such systems, it is possible to customise designs, e.g., the distribution of living units. However, **these tools are targeted at designers**

and other stakeholders such as real estate developers, builders and investors, and their interfaces are complex (Mitrana, 2021). A generative system targeted for end-users in **a co-design process needs user-friendly interfaces** that do not require technical knowledge from the user.

The computerised version of the Segal method (see sub-section 2.1.5.1) and the HOPLA-Home Planner, developed by Kwieciński & Słyk (2023), exemplify tools intended for end-users' use to create customised housing without requiring technical knowledge, through tangible interfaces that support their actions through responsive generative systems. Frazer's system, created in the 1980s, allowed to assemble a kit of parts into a model on top of an electronic panel that could automatically scan the parts and generate drawings and three-dimensional views (Frazer et al., 1982). The system could also make calculations and simulations to give feedback to the users' input, acting as a design assistant (Doe, 2018). Frazer's computational tool embeds the architect's knowledge and experience through the design rules, thus ensuring the feasibility of the inhabitants' designs. A similar approach is the HOPLA-Home Planner, developed by Kwieciński & Słyk (2023). The authors developed a generative system based on parametric design that responds to user actions using a tangible interface to move parts of physical models. However, the authors experienced difficulties with the tangible interface in user tests, and a new version was created to be used on a touchscreen device.

Other rule-based generative design systems were developed to respond to the issue of housing customisation by inhabitants. Some of them are research prototypes developed to automatically generate housing solutions that respond to the user inputs introduced in the first steps of the system's use. Examples are MALAG (Duarte & Correia, 2006), Barcode Housing System (Madrazo et al., 2010), i_Prefab Home (Huang & Krawczyk, 2007), and ABC-based Customized Mass-Housing Generator (Benrós & Duarte, 2009). These systems provide a set of parameters that can be adjusted to correspond to the user's needs. Another group of prototypes, which do not start with the introduction of requirements, helps the user to create the house layout step by step according to the decisions taken through the design process. Examples of such generative design tools are HouseMaker (MVRDV & Axis.fm, 2012), Group Forming (Ong et al., 2013), and ModRule (Lo et al., 2015).

Also, commercial solutions such as IKEA Kitchen Planner (Inter IKEA Systems B.V., 1999), Sweet Home 3D (ETeks, 2006), and Room Sketcher (RoomSketcherAS, 2007) were developed. Such systems allow end-users to customise their own living spaces (including the layout, finishings, and furniture), designing them from scratch according to their preferences. The designs generated by these last couple of tools, **intended to be used only by end-users**, are not generative and do not incorporate regulations or good architecture practices and, therefore, can **create designs that mislead users** about their functionality and construction viability.

In this work, an analysis was conducted on various computer systems, including those mentioned above, that were developed as auxiliary tools for the design of customised housing over the last 40

years. An overview of some of their interfaces is shown in Figure 18. These systems are categorised by different characteristics to identify the strengths and weaknesses of each one. These categories include: 1) process of generating the solutions; 2) target users; 3) type of outcome; 4) type of interaction with the system; and 5) availability of the system. The next subsections refer to systems analysis within these categories.

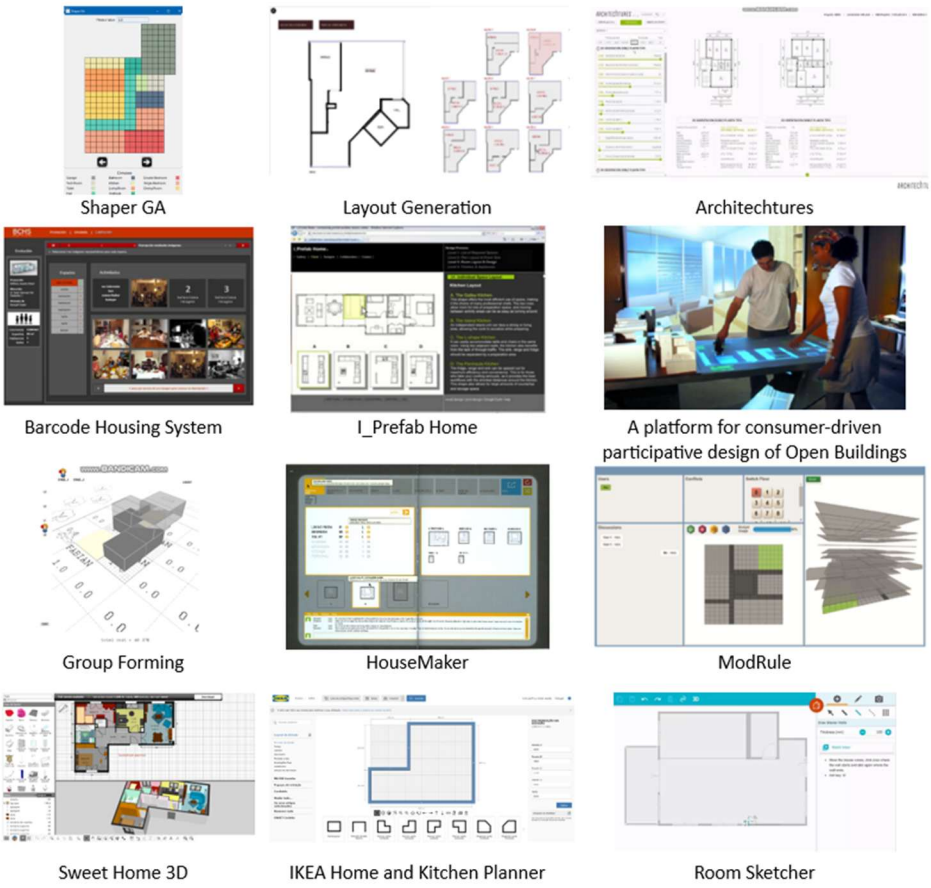


Figure 18_Interfaces of some of the analysed systems. Interfaces of some of the analysed systems. Sources: ***Shaper GA****: Kwiecinski et al., (2016, p. 357);* ***Layout Generation****: image adapted from Veloso, Celani and Scheeren (2018, p. 232);* ***Archictechtures****: Architechtures website (https://architechtures.com/?lang=en_US);* ***Barcode Housing System****: Madrazo et al. (2007, p. 158);* ***I_Prefab Home****: Huang and Krawczyk (2007, p. 566);* ***A platform for consumer-driven participative design of Open Buildings****: Mcleish (2003, p. 65);* ***Group Forming****: https://vimeo.com/26638743;* ***HouseMaker****: MVRDV and Axis.fm (2012, p. 176);* ***ModRule****: Lo, Schnabel and Gao (2015, p. 246);* ***Sweet Home 3D****: Sweet Home 3D website (https://www.sweethome3d.com/pt/);* ***IKEA Home and Kitchen Planner****: IKEA website (https://kitchenplanner.ikea.com/au/UI/Pages/VPUI.htm), currently not available;* ***Room Sketcher****: Room Sketcher website (https://www.roomsketcher.com/).*

2.3.2.1 Generation process

2.3.2.1.1 Systems that generate in one step the final design of a new house

Some systems aim at generating in one step the final design of a house, showing it to the end user and omitting from them the stages of generation. These systems exist for both new construction and for refurbishment purposes. For new construction, the **Barcode Housing System** (Madrazo et al., 2010) automatically generates housing layouts that are filtered and presented to the user based on the

requirements defined by the inhabitants. Also, **i_Prefab Home** (Huang & Krawczyk, 2007) generates housing design and assists in selecting appropriate building components for prefabricated housing. **Haiti grammar** (Benrós et al., 2011) generates the design of customised Haiti Colonial houses for post-Earthquake, and **Shaper GA** (Taborda et al., 2018) generates different customised wood housing solutions based on the requirements introduced by the user. The system presents a set of possible solutions that accomplish the requirements through which the user can navigate to choose the final design.

For housing transformations and refurbishments **Rabo de Bacalhau Transformation Grammar** (Eloy & Duarte, 2015) enable inhabitants to obtain a customised automatic design for the refurbishment of their house in the *Rabo de Bacalhau* style. The aim of the **Bourgeois houses Porto grammar** (Coimbra & Romão, 2013) is also to provide a tool that creates alternative design solutions for the refurbishment of a specific house type in Oporto. The **Vernacular Hayat houses grammar** (Colakoglu, 2005) generates new house designs based on the original language of the Hayat style.

Some other systems aim at generating a design of a house that already exists for analysis purposes. Solutions using analytical shape grammars are used in most of these cases. Examples are **MALAG** (Duarte & Correia, 2006), a design system based on the shape grammar created by Duarte (2005), that generates houses in Malagueira neighbourhood, in Portugal, designed by the architect Siza Vieira, the **Favela Rocinha houses grammar**, in Brazil, (Dias et al., 2013), the **Taiwanese traditional vernacular dwellings grammar** (Chiou & Krishnamurti, 1995), and the **Traditional Turkish houses grammar** (Çağdaş, 1996).

2.3.2.1.2 Systems that generate the design of a new house by steps

Some systems aim at generating a design of a new house step by step, allowing users to make decisions during the house design generation. Some examples of such systems are **ModRule** (Lo, Schnabel and Gao, 2015), **Group Forming** (Ong, Janssen and Lo, 2013), **Layout Generation** (Veloso, Celani and Scheeren, 2018), **A_Shaper** (Santos *et al.*, 2018), and **HouseMaker** (MVRDV and Axis.fm, 2012). Also, in the commercial sector, some systems support the design of houses or parts of houses in a step-by-step manner. Examples are the **Room Sketcher** (RoomSketcherAS, 2007) and the **Sweet Home 3D** , **3D** (ETeks, 2006), to create customised houses, and **Architechtures** (SmartScapes Studio SL, 2019) that generates multi-dwelling buildings and uses parametric design to generate different layouts by changing the parameters.

2.3.2.1.3 Systems that generate in one step a part of a new house and leave a part to be generated by steps

Some other systems generate in one step part of the house and leave other parts to be generated step by step, allowing users to make decisions during the house design generation. The **ABC-based Customized Mass-Housing generator** (Benrós and Duarte, 2009) is a tool to generate and support the design of mass-customised houses. A 3D model is automatically generated based on the decisions taken by the user, and the tool then assists the user in the spatial organisation of the functional units. Also, the **Web-based user-oriented tool for universal kitchen design** (Ma, 2002) generates design solutions that are retrieved to present the most fitted solutions based on the family's requirements, and also supports the user in the final stage to choose the appropriate kitchen equipment based on the rules of universal design. The **platform for consumer driven participative design of Open Buildings** (Mcleish, 2003) is a system that enables inhabitants to co-design their houses or studios within the Open Building concept. The system generates the initial design and also allows the user to refine the layout step by step. The **IKEA Kitchen Planner** (Inter IKEA Systems B.V., 1999) also generates suggestions based on the user's initial requirements and allows them to refine the design by changing spatial characteristics and adding furniture.

2.3.2.2 Target users

2.3.2.2.1 Architects

Some of the systems under analysis are, according to the authors, designed to be used by professionals. Some of them, as **Bourgeois houses Porto grammar** (Coimbra and Romão, 2013), **Vernacular Hayat houses grammar** (Colakoglu, 2005), **Favela Rocinha houses grammar** (Dias, Gani and Chokyu, 2013), and **Taiwanese traditional vernacular dwellings grammar** (Chiou and Krishnamurti, 1995) are designed for architects. For some of them, the use still presupposes design and programming skills that non-designers do not have. The **Traditional Turkish houses grammar** (Çağdaş, 1996) is designed, according to the authors, to facilitate the understanding of Turkish houses by architecture students in order to incorporate this knowledge in future housing designs.

2.3.2.2.2 Clients

Other systems are targeted at the clients themselves, whether it is the end user (inhabitants) or the building promoter. Examples of systems targeted for inhabitants are **Rabo de Bacalhau Transformation Grammar** (Eloy and Duarte, 2015), **Shaper-GA** (Taborda *et al.*, 2018), **A_Shaper** (Santos *et al.*, 2018), **Web-based user-oriented tool for universal kitchen design** (Ma, 2002), **IKEA Kitchen Planner** (Inter IKEA Systems B.V., 1999) and **Sweet Home 3D** (ETeks, 2006). The **HouseMaker** (MVRDV and Axis.fm, 2012) is also targeted for inhabitants and allows them to remotely communicate

with family or friends to define the characteristics of the house, while they are assisted by an operator. **Architechtures** (SmartScapes Studio SL, 2019) is an online mass-housing design system designed to be used by the promoter of a building block. **MALAG** (Duarte and Correia, 2006), **i_Prefab Home** (Huang and Krawczyk, 2007) and **Room Sketcher** (RoomSketcherAS, 2007) can also be handled by architects, although their main target is the inhabitants.

2.3.2.2.3 Architects and inhabitants

There are also collaborative systems that allow the participation of different stakeholders and also the communication between multiple end-users. **Barcode Housing System** (Madrazo *et al.*, 2010) and the **platform for consumer-driven participative design of Open Buildings** (Mcleish, 2003) enable the participation of designers, end-users and manufacturers at different stages of the process. **ModRule** (Lo, Schnabel and Gao, 2015) and **Group Forming** (Ong, Janssen and Lo, 2013) are handled by architects and inhabitants at different stages, but also allow the collaboration between multiple end users in order to create mass housing solutions that every user is satisfied with. **Layout Generation** (Veloso, Celani and Scheeren, 2018) is used by architects and inhabitants at each stage, and also allows the collaboration between them at the final stage to choose finishings. The **ABC-based Customized Mass-Housing generator** (Benrós and Duarte, 2009) and the **Haiti grammar** (Benrós *et al.*, 2011) are used by architects and foresee the inhabitant to be present during the decision-making process.

2.3.2.3 Type of design outcome

2.3.2.3.1 Simplified floor plan

Some systems deliver a simplified floor plan, which, e.g. defines the functional areas of the house but does not give construction information. **A_Shaper** (Santos *et al.*, 2018) and **Shaper-GA** (Taborda *et al.*, 2018) give as an outcome a simplified layout of a house. This layout is based on a grid composed of squares of 60x60cm. A set of squares composes a room, and each type of room has a different colour. The **Vernacular Hayat houses grammar** (Colakoglu, 2005), **Favela Rocinha houses grammar** (Dias, Gani and Chokyu, 2013), **Taiwanese traditional vernacular dwellings grammar** (Chiou and Krishnamurti, 1995), and **Traditional Turkish houses grammar** (Çağdaş, 1996) results are represented with shapes that figure schematic floorplans.

2.3.2.3.2 Detailed floor plan

Other systems generate detailed floorplans with indication of walls, openings and large-scale construction information as materials and construction systems. Such systems are **Rabo de Bacalhau Transformation Grammar** (Eloy and Duarte, 2015), **Bourgeois Oporto houses transformation grammar** (Coimbra and Romão, 2013), and **Group Forming** (Ong, Janssen and Lo, 2013). In the **Web-**

based user-oriented tool for universal kitchen design (Ma, 2002), the floorplans also include kitchen equipment.

2.3.2.3.3 Drawings and 3D house design

In addition to detailed drawings, some systems generate 3D models that provide interior or aerial views. In the **HouseMaker** (MVRDV and Axis.fm, 2012) the results of the options made are presented in 2D or 3D, according to the type of element that is being defined, and it can be shared, printed, sent by email and purchased. Also **Room Sketcher** (RoomSketcherAS, 2007) provides 2D floorplans, interior views and a 3D walkthrough mode, as well as **Barcode Housing System** (Madrazo *et al.*, 2010) and **ModRule** (Lo, Schnabel and Gao, 2015) that generate detailed floorplans from simplified representations. The latter also allows a virtual reality visualisation with FuzorVDC (Kalloc Tech Studios, 2021).

2.3.2.3.4 Drawings, 3D house design and Lists

Other systems generate 2D drawings, 3D models that provide different types of visualisation and lists of building elements and budget. Examples of such systems are the **i_Prefab Home** (Huang and Krawczyk, 2007), **ABC-based customised mass-housing generator** (Benrós and Duarte, 2009), **Haiti grammar** (Benrós *et al.*, 2011), **MALAG** (Duarte and Correia, 2006), and **Layout generation** (Veloso, Celani and Scheeren, 2018). The **platform for consumer driven participative design of Open Buildings** (Mcleish, 2003) can also generate list of components, informing their positions, and finishing options made by the user. **Sweet Home 3D** (ETeks, 2006) generates, besides the floorplan and 3D, a printable furniture list, and the **IKEA Kitchen Planner** (Inter IKEA Systems B.V., 1999) generates the list of all the store's products included in the design. **Architechtures** (SmartScapes Studio SL, 2019) generates a viability analysis and the entire architectural definition and construction elements, with building services, prepared for city permits. The outcome is generated in CAD, BIM and Excel formats.

2.3.2.4 Type of interaction with the system

2.3.2.4.1 Start by defining user preferences

This category includes all the systems that the generation process starts with the introduction of user preferences regarding space requirements and characteristics of the household. Those systems generate design solutions based on initial user requirements, and then, the users can change the requirements to achieve different solutions until they are satisfied. Examples of such systems are **Rabo de Bacalhau Transformation Grammar** (Eloy and Duarte, 2015) that starts with the introduction of users' requirements, **i_Prefab Home** (Huang and Krawczyk, 2007), where a user defines the requirements through questionnaires and icon selection and then can select the preferred solution

and choose the finishings, **MALAG** (Duarte and Correia, 2006), that generates on the *PROGRAMA* interface the design brief as a list of space requirements to be introduced on the *DESIGNA* interface to create the design solution, and **Shaper-GA** (Taborda *et al.*, 2018), that generates a bank of solutions based on the requirements data introduced, through which the user can navigate until they find the most fitted or change the requirements to generate different ones. Also, the **Web-based user-oriented tool for universal kitchen design** (Ma, 2002) can generate solutions based on the information introduced and update the results as the requirements are changed. This tool also enables to drag and drop universal design kitchen products and assists the user with recommended solutions. The refining process of the design generated by the **platform for consumer driven participative design Open Buildings** (Mcleish, 2003) is made by interacting with physical models on an interactive table, and the system updates the design (as the user moves the models), identifies problems and suggests solutions. The **HouseMaker** (MVRDV and Axis.fm, 2012) categorises all the elements of a house regarding materials, shapes, rooms, layout, etc. Although there is not a mandatory sequence, the user starts by defining the room characteristics.

2.3.2.4.2 Start not by defining user preferences

This category includes all the systems that the generation process does not start with the introduction of user preferences. **ModRule** (Lo, Schnabel and Gao, 2015) and **Group Forming** (Ong, Janssen and Lo, 2013) start by generating a grid with parameters and spatial rules defined by the architect, and then, multiple end users negotiate with each other to fill the grid and define their houses. To define the interior layouts, ModRule allows users to drag room types and make connections. In other mass housing systems, referred to below, architects start with the definition of the overall rules and characteristics of the building, with fixed elements and common spaces, and then the inhabitants define the interior of their houses. Such systems are **Barcode Housing System** (Madrazo *et al.*, 2010), and **ABC-based customized mass-housing generator** (Benrós and Duarte, 2009). The interaction of **Layout generation** (Veloso, Celani and Scheeren, 2018) is performed by steps where, initially, an open space is divided into smaller rooms and then the system presents the next possible steps. In commercial systems, such as **Room Sketcher** (RoomSketcherAS, 2007), **Sweet Home 3D** (ETeks, 2006), and **IKEA Kitchen Planner** (Inter IKEA Systems B.V., 1999), users can choose architectural elements and, with them, design a house in a semi-random way. **A_Shaper** (Santos *et al.*, 2018) starts with the generation of a grid that represents the dimensions of the house, and the sequence of actions includes assigning in a specified order the entrance, the semi-public spaces and, finally, the private zones. **Architechtures** (SmartScapes Studio SL, 2019) starts with the definition of the external configuration of the building. The dwellings' typologies and interior layout are then defined by the user and is also possible to control the façade characteristics The authors of **Bourgeois Oporto houses transformation**

grammar (Coimbra and Romão, 2013) do not define the type of interaction although the process implies defining functional zones and further the division into smaller rooms on each floor until reaching the final result. The **Haiti grammar design system** (Benrós *et al.*, 2011), **Vernacular Hayat houses grammar** (Colakoglu, 2005), **Favela Rocinha houses grammar** (Dias, Gani and Chokyu, 2013), **Taiwanese traditional vernacular dwellings grammar** (Chiou and Krishnamurti, 1995), and **Traditional Turkish houses grammar** (Çağdaş, 1996) comprehend different stages of rule application, although the authors do not specify the mode of interaction of the user with the systems.

2.3.2.5 Availability of the system

2.3.2.5.1 Available online for free

IKEA Kitchen Planner (Inter IKEA Systems B.V., 1999) is available online for free (at https://kitchen.planner.ikea.com/pt/pt/planner/). **Room Sketcher** (RoomSketcherAS, 2007) can be used by installing the application on a computer or tablet. The application can be downloaded from the website (https://www.roomsketcher.com/). **Sweet Home 3D** (ETeks, 2006) is also a free system that can be used in two ways: (1) online, using the Sweet Home 3D Online Manager (https://www.sweethome3d.com/SweetHome3DOnlineManager.jsp) as a demo version, or (2) downloading the application to have access to the full version.

2.3.2.5.2 Available on request/payment

In **Room Sketcher** (RoomSketcherAS, 2007) not every feature is available for free, as the system has a premium subscription that enables the access to every feature. **Architechtures** (SmartScapes Studio SL, 2019) is available under payment, although it has a 7-day free trial through the website (https://architechtures.com/).

2.3.2.5.3 Not available

Some systems have been implemented or partially implemented as prototypes and are not available online for free, nor have they been announced to be available under request. Examples are **A_Shaper** (Santos *et al.*, 2018), **Shaper-GA** (Taborda *et al.*, 2018), **ModRule** (Lo, Schnabel and Gao, 2015), and the **platform for consumer driven participative design of Open Buildings** (Mcleish, 2003). Also, prototypes of the **ABC-based customized mass-housing generator** (Benrós and Duarte, 2009) and **Haiti grammar** (Benrós *et al.*, 2011), developed to run on AutoCAD and Revit Architecture software, respectively, are not available. The **Rabo de Bacalhau Transformation Grammar** (Eloy and Duarte, 2015), partially implemented by Strobbe et al. (2016), **HouseMaker** (MVRDV and Axis.fm, 2012), **Web-based user-oriented tool for universal kitchen design** (Ma, 2002), **i_Prefab Home** (Huang and Krawczyk, 2007) and **Layout Generation** (Veloso, Celani and Scheeren, 2018), and **Barcode Housing**

System (Madrazo *et al.*, 2010) are prototypes not available as design tools. **Group Forming** (Ong, Janssen and Lo, 2013) prototype has been envisioned as a web application and is currently not available, although an explanation about the system is available at (https://vimeo.com/26638743). The **MALAG** prototype (Duarte and Correia, 2006) was envisioned to be used online or as a PC application, although the system is not available as a design tool.

There are also shape grammar systems that are intended to generate housing designs, although they have not been implemented as computational systems. **Bourgeois Oporto houses transformation grammar** (Coimbra and Romão, 2013), **Vernacular Hayat houses grammar** (Colakoglu, 2005), **Favela Rocinha houses grammar** (Dias, Gani and Chokyu, 2013), **Taiwanese traditional vernacular dwellings grammar** (Chiou and Krishnamurti, 1995), and the **Traditional Turkish houses grammar** (Çağdaş, 1996) are examples of such design systems.

2.3.2.6 Synthesis of system's characteristics

Table 3 presents a synthesis of the classification made. The table summarises the characteristics of the systems analysed above, within the defined criteria. The *Process* column refers to the analysis made to the generation process; *Users* is for the target users; *Outcome* representation presents the type of design outcome; *SM* is a complement to the type of interaction with the system criteria, and defines whether the systems have (or not) the ability to directly manipulate the space; and, finally, *Av/Imp* column shows the characteristics analysed in the system availability criteria.

Table 3_Synthesis of system's characteristics

Name	Generation Process			Target Users			Type of design outcome						SM	Av
	GN	SN	G/SE	A	I	O	SP	DP	SD	DD	3D	L		
Taiwanese traditional vernacular dwellings grammar (1995)			X	X			X						N	N
Traditional Turkish houses grammar (1996)			X	X			X						N	N
IKEA kitchen planner (1999)	X	X			X					X	X	X	Y	A
Web-based user-oriented tool for universal kitchen design (2002)	X	X			X			X					Y	P
A platform for consumer driven participative design of Open Buildings (2003)	X	X		X	X			X			X	X	Y	P
Barcode Housing System (2003-10)	X			X	X	X				X	X		N	P
MALAG (2005-10)	X		X		X			X			X	X	N	P
Vernacular Hayat houses grammar (2005)	X			X			X						N	N
Sweet Home 3D (2006)		X			X			X			X	X	Y	A
i_Prefab home (2006-07)	X				X					X	X	X	N	P
Room Sketcher (2007)		X			X			X			X		Y	A
ABC-based Customized Mass-Housing generator (2007/09)	X	X		X	X					X	X	X	Y	P
Haiti grammar (2011)	X			X	X					X	X	X	N	P

Rabo de Bacalhau Transformation Grammar (2011-16)	x				X			X					N	P
HouseMaker (2012)		X			X					X	X		N	P
Group Forming (2013)		X		X	X					X			Y	P
Bourgeois Oporto houses transformation grammar (2013)	X			X				X					N	N
Favela Rocinha houses grammar (2013)			X	X			X						N	N
ModRule (2014-16)		X		X	X			X			X		Y	P
Shaper-GA (2016-18)	X				X		X						N	P
A_Shaper (2016-18)		X			X		X						N	P
Layout Generation (2018)		X		X	X					X	X	X	N	P
Architechtures (2019)		X			X					X	X	X	Y	A

Generation Process – **GN** (Generate New design); **SN** (Support New design); **G/SE** (Generate or Support Existing design).
Target Users – **A** (Architect); **I (**Inhabitant); **O (**Other).
Type of design outcome representation – **SP** (Simplified Plan); **DP** (Detailed Plan); **SD** (Simplified Drawings); **DD** (Detailed Drawings); **3D** (3D model); **L** (Lists).
SM – Direct manipulation of space: **Y**es, **N**o.
Availability of the system – Availability of the system: **A**vailable, **P**rototype not available, **N**ot available.

2.3.3 User-Centred Interfaces in Participatory and Collaborative Design

While digital tools have brought significant benefits to customisation and participatory and co-design processes, it is essential to address issues related to human-computer interaction and user experience. Developing user-friendly interfaces is crucial so inhabitants can easily interact with the design. Kwieciński and Słyk (2023) defend that **generative design technologies should be integrated with user-friendly interfaces**. Madrazo et al. (2007) highlight the need for user-friendliness by stating that a general requirement for end-user participation is the need "to create appropriate interfaces that facilitate a dialogue with a user in a language suited to the knowledge a user has at each stage of the process" (Madrazo *et al.*, 2007).

Although effective customisation and participation need tools to combine the potential of generative design with user-friendly interfaces, no evidence was found in the literature of the development tools involving potential users. **Although the mentioned tools make important contributions to housing customisation, there is no evidence in the literature that their interfaces were specifically designed for inhabitants as end-users or developed in collaboration with them**

User-centred design aims to develop products that are easy to use. Actively involving end-users in the development process and evaluating them iteratively leads to products that meet their real requirements and facilitate their satisfaction. Gonçalves, Fonseca and Campos (2017) state that, although developing computational tools can be time-consuming, usability engineering offers benefits in terms of development cost, quality of the final product, and user satisfaction. Design problems can be detected at an early phase, which saves time and money. The authors explain that, instead of developing full operational systems before users test their interfaces, which may require significant changes, prototyping aims to reduce the time and cost of this development process.

Low-fidelity prototyping, e.g. paper prototypes, allows for quickly testing features without spending too many resources to identify usability problems that can be solved at a preliminary phase (Rettig, 1994). On the other hand, high-fidelity functional prototypes allow to extract usability measures that paper prototypes do not allow, such as efficiency (which measures the time to perform a task), for allowing to simulate the dynamic feedback of the system (Maguire, 2001; Gonçalves, Fonseca and Campos, 2017).

Figma, Adobe XD, and InVision are examples of tools that allow the creation of high-fidelity prototypes. What these tools have in common is their ability to create functional prototypes without any code and share them with other stakeholders. Figma (Figma Inc, 2016) is a collaborative web app, although it also has a desktop application version. This codeless interface design tool allows the creation of high-fidelity prototypes with some interaction possibilities that simulate the feedback of the system whose interface is under development. Adobe XD (Adobe Systems, 2016) is another tool for User Interface (UI) and User Experience (UX) design. The clipboard-based workflow is similar to Figma and allows the design of different screens and connecting them, adding animations to create interactive prototypes. Similar to both tools mentioned above, InVision (InVisionApp Inc, 2011) is also a web app that can create user interfaces for websites or apps for multiple devices, with screen connections that simulate the system's feedback to users' actions in a collaborative environment.

Figma is one of the developers' most commonly used design tools for web interfaces and mobile applications for its ease of use (Staiano, 2022). The literature shows that it is used to develop interfaces in various fields, such as health and nutrition (Putra, Ajie and Safitri, 2021), digital tourism (Al-Faruq, Nur'aini and Aufan, 2022; Mustika *et al.*, 2024), apps for ordering home services (Efendi *et al.*, 2022), and the financial sector for managing loans for agricultural activities (Sudjiran, Saefudin and Perdana, 2023). In both of the mentioned examples, the authors used Figma as the prototyping tool within a user-centred design framework, using methods such as Design Thinking and lean UX in the iterative development process. Using a user-centred design methodology is paramount to achieving an interface that meets users' needs. It is necessary to involve end users iteratively, using low and high-fidelity prototypes in various design development phases rather than just testing a final product.

CHAPTER 3: Gathering of users' needs through interviews

This chapter presents the results from interviews conducted to identify in practice how participatory processes occurred or could ideally occur and how digital tools can help these processes (step 1 of the iterative process explained in 1.3.2). Fifty-eight interviews were conducted with three different groups: twenty-eight **professionals from architecture**, **urbanism, and social sciences** areas; ten **housing cooperatives** representatives; and twenty **inhabitants** living in houses from those cooperatives.

The interviews with professionals focused on their opinions about three aspects: (1) the need for housing customisation, (2) the participation of end-users in the design process, and (3) the use of digital technologies in participatory processes.

The interviews with housing cooperatives aimed to identify how these institutions work regarding the design of new housing and whether inhabitants participated or expressed their willingness to participate in the design process of their houses. This research focuses on housing cooperatives as an example of a multi-family housing context in which end-users are known prior to construction, enabling them to be invited to participate in the design process. Also, as shown by (Sardinha & Carvalho, 2007), inhabitants seek housing cooperatives for a more affordable price, however, they feel unsatisfied with the houses they acquire (see section 2.1.6.6), which highlights an opportunity for the proposed interface.

From the interviews with inhabitants, their perspectives on the process they were involved in were collected, regarding how they participated and how this could be improved. The questions focused on three phases: 1) the participation process they were involved in, 2) their satisfaction with the process and the design outcome, and 3) how a digital tool could help them to participate more actively in the design definition. The third part aimed to define aspects of the tool, such as functionalities (design phases in which they would like to participate) and types of visualisation and interaction that could facilitate the participatory task.

3.1 Population and sample

The professionals were selected according to their professional practice: architecture, urbanism, social sciences, and other professions related to housing or co-design. Professionals and architecture offices that were previously involved in participatory practices or who work within the mentioned areas were identified in the literature and in an internet search. At the end of the interview, a snowball sample method was used to gather other participants by asking them to suggest other professionals who would fit the interview purposes. The contacts were managed, keeping a balance between the number of national and foreign interviewees. The institutions were selected through a search of

Portuguese housing cooperatives. Housing cooperatives and residents' associations across the Portuguese territory were contacted, and, among a set of 60 cooperatives initially contacted, the ten interviewed were the ones who agreed to collaborate on the research. The inhabitants of housing cooperatives were recruited through a request to the cooperative representative to invite the inhabitants to participate in the interviews. The criterion was that the inhabitants should be the house's first-ever tenants rather than someone who acquired the property later, through purchase from another tenant, as they did not participate in any phase of the design and construction process. Those interested in participating, permitted the cooperative representative to provide their contact details so they could be contacted to schedule the interview.

The professionals who participated in the interviews were recruited between June 1st 2021, and September 12th 2021. The representatives of housing cooperatives and inhabitants were recruited between October 18th 2021 and November 29th 2021.

3.2 User study method

The interviews were semi-structured with **open-ended questions**, as the goal was to explore the issues addressed as qualitative data and not limit the answers to predefined options. However, in the third part of the interviews with the inhabitants (see sub-section 3.5.2.3), closed-ended questions were used because the goal was to obtain specific data for defining the requirements of a user-centred interface for such a digital tool. Therefore, along with the questions, examples of types of visualisation, interaction, and devices to be chosen by respondents were shown. Recognising that the interviewees may not possess technical expertise in architecture, straightforward language accessible to all was used. The questions formulated are listed in Appendix A

The interviews were mainly conducted online during 2021 and were recorded (audio and image, with the explicit consent of the interviewee) through the Zoom platform. They lasted between 60 and 90 minutes. In some cases, the interviews were conducted in person, at the request of the interviewees, with an audio recording. Since the interviews were conducted within a period still affected by the Covid-19 pandemic, this mixed method was considered the most appropriate. All respondents agreed to participate in the interviews, according to a consent form and user study protocol approved by the Iscte—Instituto Universitário de Lisboa Ethics Committee. The informed consent was obtained verbally and documented in video recording through the Zoom platform. To protect their identity, they were pseudonymised according to the group of interviews. Professionals were pseudonymised as P1, P2, P3, etc. Cooperative representatives are identified as C1, C2, C3, etc. and Inhabitants as I1, I2, I3, etc.

The steps followed to carry out the interviews were as follows: (a) Definition of the interview model: open-ended questionnaire and closed-ended questionnaire (in the case of the third part of the interview with the inhabitants); (b) Contact with potential interviewees; (c) Carrying out interviews; (d) Analysis of interviews; (e) Systematisation of results and definition of conclusions. For the systematisation of results, the answers were grouped according to the similarity of topics addressed by the interviewees. The results of the interviews with each group are reported in the following sub-chapters.

3.3 Interviews with professionals from Architecture, Urbanism and Social Sciences

This sub-chapter analyses and relates the opinions of two groups of professionals regarding the inclusion of inhabitants in the design process of their houses. **The interviews aimed to collect information on how participatory processes occur and could occur, what the best methods and strategies for interaction with a group of end users are, and how digital technologies can improve these processes**.

Although the questions were semi-structured, the script was flexible with the possibility of adapting the interview to the interviewee and the circumstances (e.g., if the professional was not an architect, questions about an architect's point of view were not asked).

Interviews were defined for two distinct groups of professionals:

Group A: Professionals with experience in participatory processes. These interviews focused on the report of a specific case to understand how the process took place and what strategies were used.

Group B: Professionals who do not practice participatory processes but work with housing in their professional practice. These interviews focused on the professionals' opinions regarding housing customisation, the inclusion of inhabitants in the design process, and how this could occur or be improved.

3.3.1 Sample

The sample of interviewed professionals is represented in Table 4, which shows the context in which the professionals work. To maintain interviewees' anonymity, their identification was replaced by a code (i.e., P1, P2...).

The column **"Profession"** indicates the profession of the interviewee, who was selected for his relationship with the interview subjects: architecture, social sciences, housing, participatory processes, and co-design. **"Experience in participatory projects"** refers to the type of interview carried out, according to the groups mentioned above: **Group A:** professionals with experience in participatory

processes and **Group B**: professionals who do not practice participatory processes. The column **"Country"** refers to the location where the project was developed (in the case of Group A) and where the interviewee works in their professional practice (in the case of Group B).

Information about **"Project typology"** refers to the field the professionals work in or the field of the specific project they reported during the interview: "Housing" refers to housing projects; "Public space" refers to small public spaces such as a square or a park; "Urban design" refers to a larger scale and includes the built environment, streets, and facilities; "Public building" refers to buildings where public activities are held, such as cultural or working activities; "Various" means that the professionals work in more than one of these areas or other areas that can not necessarily be related to design; and "Housing management" refers to the management of housing delivery in a specific city.

The "Use of technologies in participation" and "Participation level" categories apply only to the professionals from Group A and refer to the cases reported during the interviews. Regarding the **"Use of technologies in participation"**, "Yes" means that participants interacted directly with digital technologies, whether using online platforms or handling equipment such as virtual reality glasses or interactive digital tables; "Complementary" means that digital technologies were only used by professionals to show project proposals or references to participants through slideshows or videos; and "No" means that digital technologies were not used at all during the participation process.

The **"Participation level"** is based on the Table 2 definitions. It should be noted that at the "Participation" level, end users do not make decisions or create the design (they only communicate their wishes), and at "Co-decision", they influence the decision on proposals that were not created by them. On the other hand, at the "Co-creation" level, ideas and solutions are created by participants in addition to influencing decision-making. "Co-design" refers to translating these ideas and solutions into design proposals created by the end users.

Table 4_ Professionals' work context

	Profession	Experience in participatory projects	Country	Project typology	Use of technologies in participation	Participation level
P1	Sociologist	B	Portugal	Various	-	-
P2	Architect and researcher	B	Portugal	Housing	-	-
P3	Architect	A	Portugal	Housing	No	Participation
P4	Architect	B	Portugal	Various	-	-
P5	Architect	A	Portugal	Public space	Complementary	Participation and Co-decision
P6	Director of public bodies linked to housing	B	Portugal	Housing management	-	-
P7	Sociologist	B	Portugal	Urban design	-	-
P8	Architect	A	Portugal	Housing	No	Participation
P9	Architect	A	Portugal	Public space	Complementary	Participation
P10	Architect and researcher	B	Portugal	Housing	-	-
P11	Architect	A	Germany	Urban design	Yes	Co-design
P12	Architect	B	EUA	Housing	-	-
P13	Architect and researcher	A	Portugal	Public space	Complementary	Participation and Co-decision
P14	IT professional linked to co-design	A	Germany and France	(1) Urban design (2) Public space	(1) Yes (2) No	(1) Co-design (2) Participation
P15	Architect	A	Germany	(1) Urban design (2) Public building	(1) Yes (2) No	(1) Co-design (2) Participation
P16	Director of public bodies linked to housing	B	Portugal	Housing management	-	-
P17	Architect	B	Portugal	Housing	-	-
P18	participatory projects facilitator	A	Netherlands	Various	Yes	Co-creation
P19	Architect	A	Chile	Public space	Complementary	Co-creation
P20	Architect and urban planner	A	Norway	Public space	No	Participation and Co-decision
P21	Sociologist and participatory projects facilitator	B	Portugal	Various	-	-
P22	Architect	A	Portugal	Housing	No	Participation
P23	Architect	A	Finland	Public building	Yes	Participation (online) and Co-creation
P24	Architect and digital design	A	Germany	Urban design	Yes	Participation (online) and Co-decision
P25	Architect	A	Belgium	Public space	Yes	Co-design
P26	Architect	B	Sweden	Housing	-	-
P27	Architecture researcher	A	Sweden	Public building	No	Co-creation
P28	Architect and urban planner	A	Germany	Public space	No	Co-creation

A total of 28 interviews were conducted with people from different professions, including architects, urban planners, architecture researchers, IT professionals linked to co-design, directors of public bodies linked to housing, sociologists, and facilitators of participatory processes.

From those 28, 17 professionals who practice participatory processes and spoke about a specific case they were involved in (Group A) were interviewed and 11 professionals with no experience in practicing participatory processes and, therefore, did not talk about a specific case but about their opinion on the issues discussed (Group B).

Fifteen professionals work in Portugal, and the remaining 13 work in other countries: four in Germany, two in Sweden, one in the Netherlands, one in the USA, one in Chile, one in France (and Germany), one in Norway, one in Finland, and one in Belgium.

Ten professionals work with housing, four with various project typologies, eight with public space, five with urban design, and three with the design of public buildings.

Seventeen professionals talked about specific cases of participatory processes, and two of them spoke about two parallel projects, which means a report of 19 specific cases of participatory processes held by the 17 professionals. Nine professionals did not use technologies in the participation process, seven did, and four used digital technologies only in a complementary way (to show proposals and references to participants).

Six participation cases were at the Participation level, in which end users were involved in defining the requirements by expressing their desires. Four professionals involved end users simultaneously at the Participation and Co-decision levels. Four professionals involved end users at the Co-creation level, and one combined Participation with Co-creation at different phases of the same process. Four professionals included end users at the Co-design level.

Seven of the ten professionals working with housing do not practice participatory processes (Group B). Of these seven, five are from Portugal, one is from the USA, and one is from Sweden. The remaining three, also from Portugal, conducted a participatory process in housing at the Participation level.

Of the six Portuguese who talked about their participatory projects, three worked with housing, including inhabitants at the Participation level, and the other three worked with public space and applied levels of participation and Co-decision.

All of those (four) who carried out processes at the co-design level used digital technologies. Three are from Germany and worked with urban design, and one is from Belgium and worked with a small public space.

3.3.2 Results

The group of 22 open-ended questions posed to the professionals is organised in subjects such as housing customisation, participatory and co-design processes, and the use of digital technologies as tools to facilitate these processes. The questions were asked according to the circumstances - for Group A (professionals who practice participatory processes and talked about a specific case), the questions were focused on the process that occurred, while for Group B, the focus was on their opinion of how a participatory process could happen.

As part of the questions related to housing customisation, interviewees were asked about the need to deliver customised houses, the advantages and disadvantages of such customisation, and if

the design of houses that are part of a collective housing context hinders the ability to design them customised. Also their opinion on including inhabitants in the design process was aked.

Questions about participation focused on ways to participate and ways of dealing with a group of people when conducting a participatory process, difficulties and reasons for the lack of participatory processes, community interest in participating, and consequences of this participation. Regarding co-design, their opinion was asked on whether inhabitants should collaborate in producing design proposals, which methods participants could use to actively contribute to the design definition, and what the limits of such collaboration should be. Group A was also asked about what had been presented to participants and how they assessed the level of participation.

Regarding questions about digital technologies, participants were asked on how digital technologies help or could help a participatory process. Furthermore, professionals from Group A - who used technologies in the participatory processes in which they were involved – were asked for their opinions on how digital tools influence the engagement and perception of space by non-experts in architecture. A question was posed on how digital tools mediate between participants' freedom and the constraints involved in designing their houses, as well as how a group of end users can collaborate using the same digital tool.

The open-ended question "**Do you think that mass housing should be customised, that is, to be adjusted to inhabitants' individual needs**?" was only posed to the professionals of Group B (Figure 19), because, with Group B, the aim was to collect their opinion, while with Group A, the intention was to collect information regarding their previous practice . It was explained that the term "mass housing" refers to houses that are part of multi-storey buildings or a complex of single-family houses in neighbourhoods. Sixty-four per cent of the total interviewees responded that houses should be customised. Thirty-six per cent of them added that this customisation should not compromise the building's flexibility or economic efficiency, and is only possible if the end-user is known. On the other hand, a few professionals answered that for them it is impossible for a mass-housing building to be simultaneously customised. twenty-seven per cent did not answer this question.

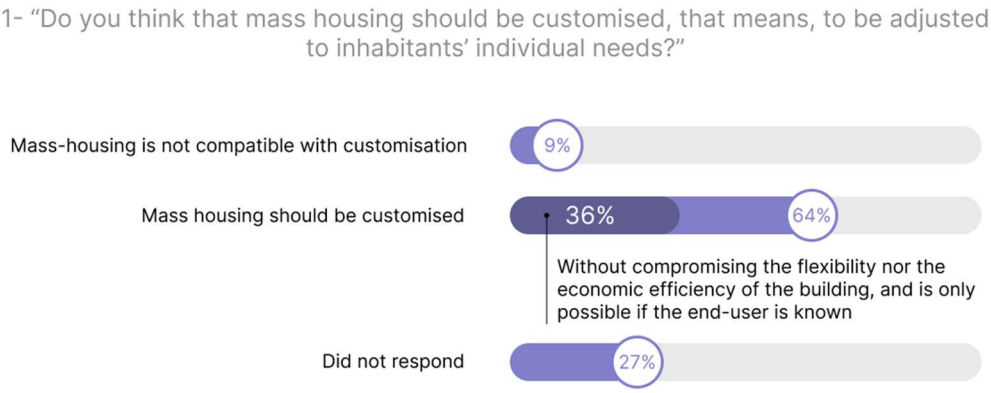


*Figure 19_Frequency of aspects mentioned by professionals (from Group B) in response to an **open-ended question** about the need for customising mass housing.*

Group B was also asked about the **advantages and disadvantages of housing customisation** (Figure 20). In this open-ended question, two advantages and two disadvantages were pointed out. The most mentioned advantage was that customisation increases the inhabitants' satisfaction with their houses, the appropriation and willingness to stay permanently in the house. This advantage was referred to by 45% of the interviewees from Group B. The other advantage was that inhabitants take better care of the customised house and have a better relationship with their neighbours. Regarding disadvantages, some professionals said that customisation is time-consuming and costly. Some other professionals argued that if customisation is too rigid, it doesn't allow the house to meet other future needs.

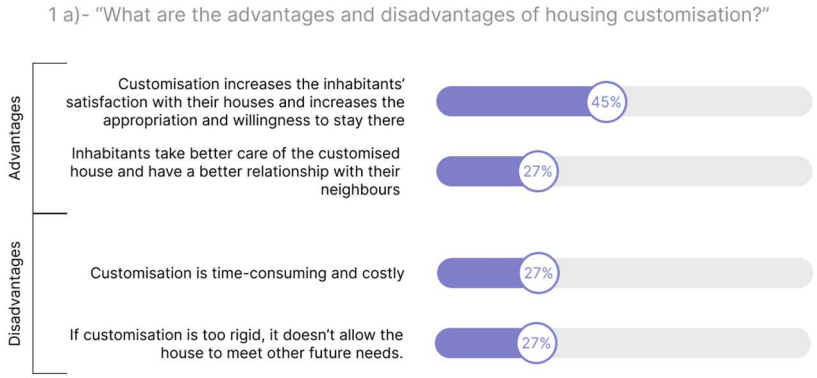


*Figure 20_Frequency of aspects mentioned by professionals (from Group B) in response to **an open-ended question** about the advantages and disadvantages of housing customisation.*

The open-ended question **"Do you think that the fact that a building (or set of buildings) is designed for mass housing hinders the ability to design in a customised way?"** was posed to both groups (Figure 21). Most of the professionals from both groups consider that mass housing hinders customisation. However, some of them highlighted that it is possible to create customised houses in such contexts if there is flexibility or the end users are known. There are a few professionals from Group A, on the other hand, who consider that mass housing does not hinder customisation since the

design can be made by standards, and the customisation occurs by choosing different compositions of the variants. Twenty-nine per cent of Group A and 27% of Group B did not responded to this question.

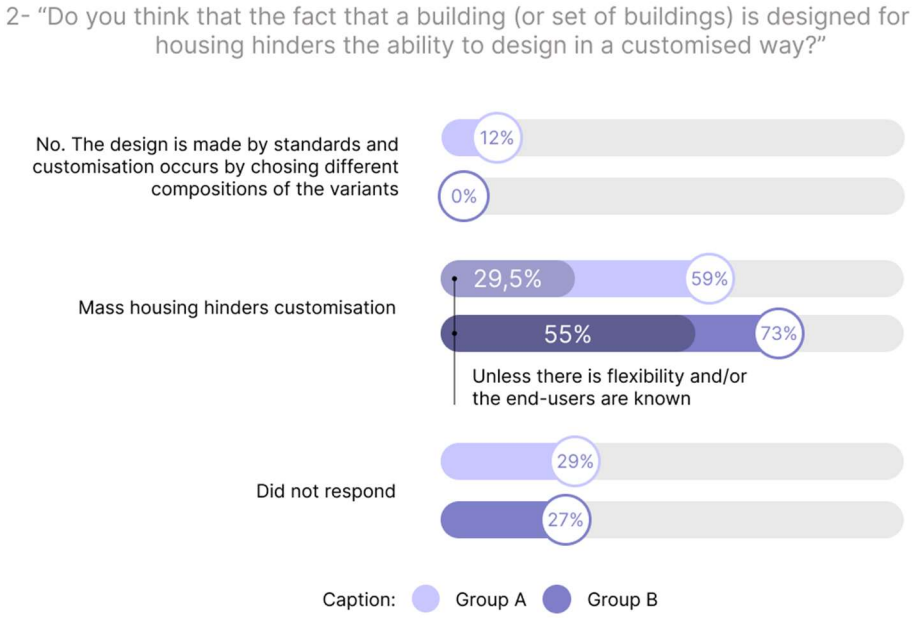


*Figure 21_Frequency of aspects mentioned by professionals (both groups) in response to an **open-ended question** about the ability to customise mass housing.*

On the participation subject, the open-ended question **"Do you think that for a house to be customised, it is essential that the end user participate in the design process?"** was posed (Figure 22). Most interviewees said participation is essential. They also added comments such as the need to know who the end-users are to conduct a participatory process, and that houses can also be modular to be flexible. Sociologists emphasise that housing is an essential good and, therefore, participation is extremely important. Opposing this answer, some professionals said that end-users do not need to participate in the design process because they will make changes anyway over time, and the house should be flexible to accommodate end-users' needs. Thirty-five per cent of Group A did not respond to this question.

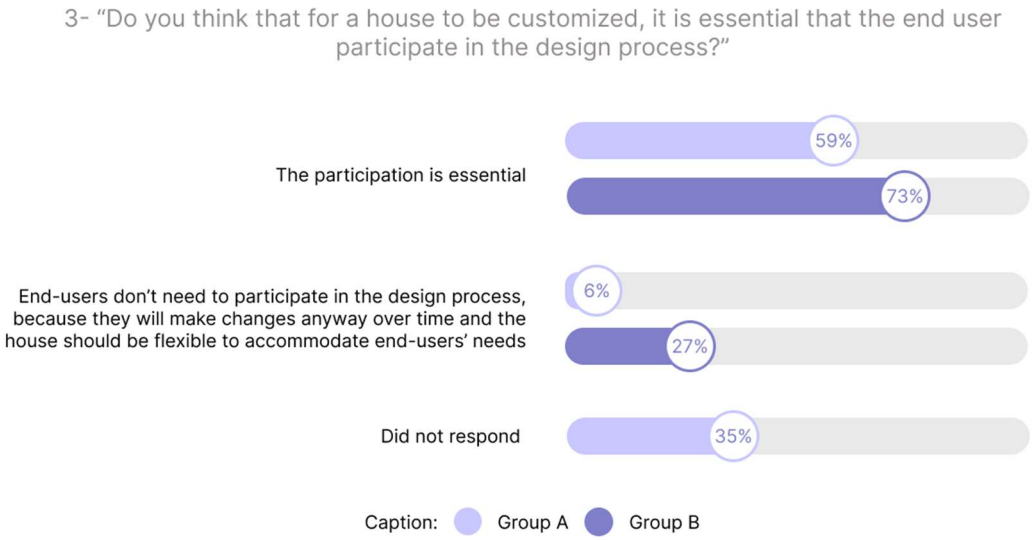


*Figure 22_Frequency of aspects mentioned by professionals (both groups) in response to an **open-ended question** about end-users' participation.*

Following this question, both groups were asked an open-ended question about **ways to participate** (Figure 23). On Group A (who spoke about a particular case), the focus was on the aspects that the participants intervened in. In Group B, the focus was on their opinion on how participation could occur.

Almost all professionals from Group A said the participants defined the requirements, gave ideas, and defined priorities. These activities were held online or in-person meetings. These professionals also involved participants in giving their opinions and making choices from design proposals prepared by architects. Another activity that some professionals from Group A held with the participants was the development of proposals in workshops. This included discussing ideas, simulations and experimentation, choices of certain aspects, and co-design. Other activities performed by the participants were mentioned by fewer professionals from this group. Such activities were the proposal of the project's location, the gathering of existing information about the houses through surveys and existing documentation, proposing ideas online, recording the process, and being involved in the construction. The gathering of existing information is related to cases where a neighbourhood was rebuilt in a different location and an intervention in a public space was made in an existing housing neighbourhood.

Regarding Group B, most professionals consider that participation can occur in meetings with end-users and technicians. Some consider that preparing a generalised design or leaving options open for inhabitants to choose from are strategies for participation, while other professionals said that inhabitants can participate through housing cooperatives. Other activities such as filling out questionnaires, workshops and context mapping were mentioned by a few professionals, as well as giving feedback after occupying the houses.

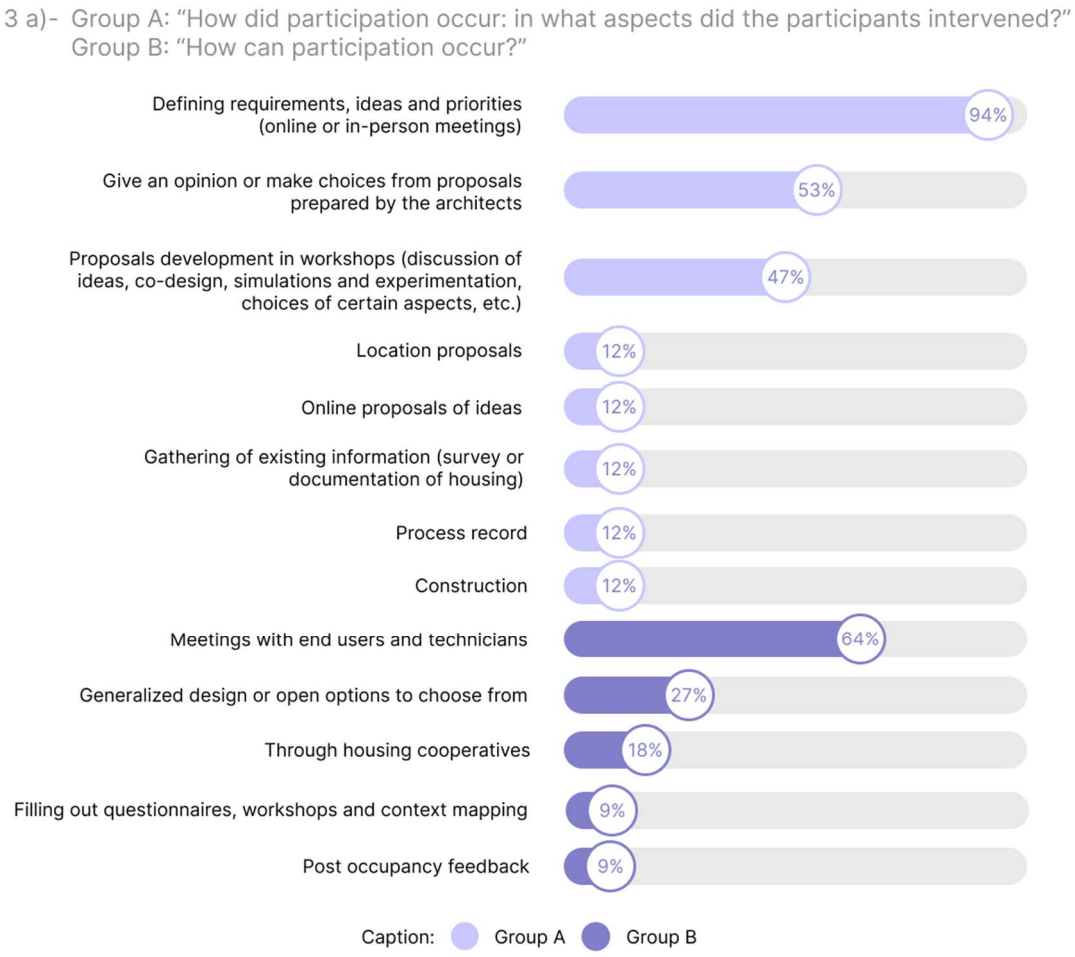


*Figure 23_Frequency of aspects mentioned by professionals (both groups) in response to an **open-ended question** about ways to participate.*

The open-ended question **"What do you consider to be the consequences of inhabitants' participation in the design of their houses?"** was asked to Group B (Figure 24). Most of them consider that participation increases ownership, satisfaction and care with the houses, and social cohesion. A few professionals also raised the possibility of innovative ideas emerging since more people are thinking about the project in participatory processes. Empowerment of society and the broadening of horizons for the architect were another positive consequence highlighted by a few professionals from Group B. On the other hand, negative consequences were mentioned by some professionals. These consequences are the risk of conflict, which leads to impasses and loss of time and money, and frustration when participation expectations are not met.

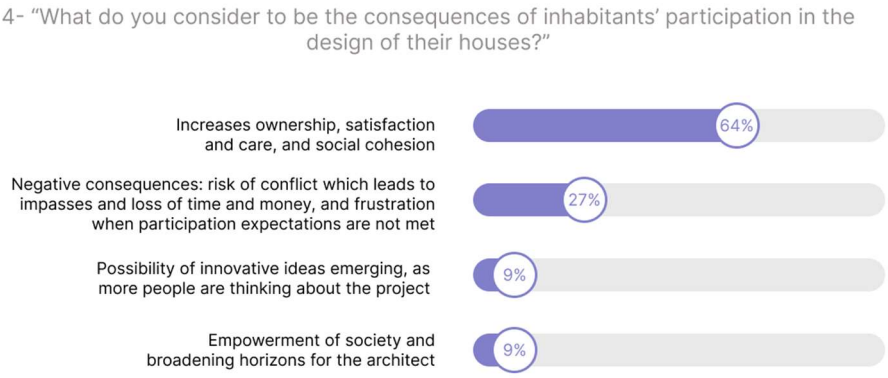


*Figure 24_Frequency of aspects mentioned by professionals (from Group B) in response to an **open-ended question** about the consequences of the inhabitant's participation.*

Both groups were asked the open-ended question **"How do you consider that an architect should deal with a group of people when conducting a participatory process?"** (Figure 25). Most of the professionals from Group B responded that a structured process should be prepared by defining a road map, clear rules, and clarifying participants' questions. The rules include defining the goals, problems, and priorities. Some interviewees (59% from Group A and 36% from Group B) agree that the architect must dialogue with the participants and understand their characteristics and skills. Some professionals also mentioned the strategy of gaining trust and empathy among the group by encouraging the sharing of experiences or in a playful way, such as through role-play games. Another good practice considered is to invite people to discuss and divide them into small groups of up to ten people. They added that the groups must have a representative because talking with too many people is difficult. Finally, a few professionals from Group B said that the architect must know how to manage different opinions and balance limitations and freedom of participation.

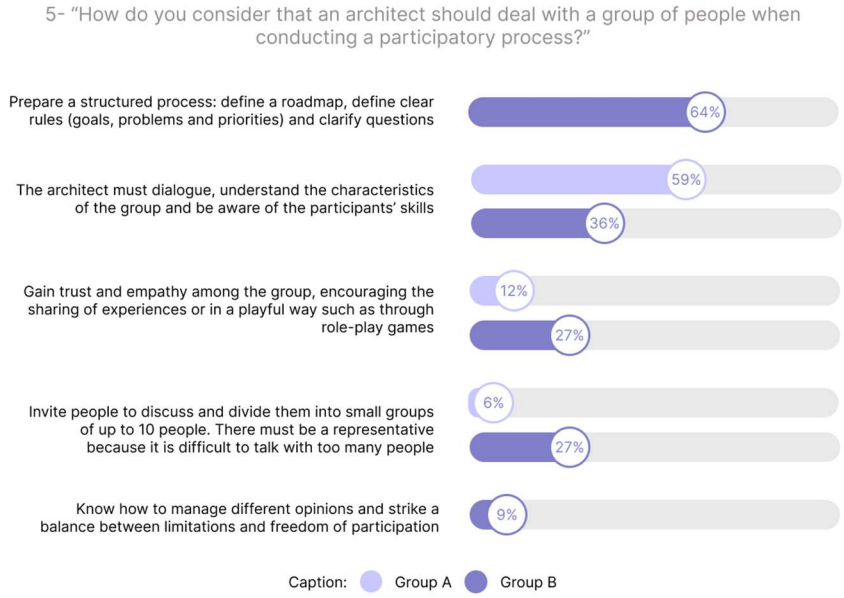


*Figure 25_Frequency of aspects mentioned by professionals (both groups) in response to an **open-ended question** about how an architect should conduct a participatory process.*

The difficulties of a participatory process were also addressed in the interviews. Group A was asked about which difficulties they experienced through the open-ended question **“What were the difficulties or limitations in the process?”** and Group B was asked the open-ended question **“What are the difficulties that cause the lack of participatory processes in architecture?”** (Figure 26). Group B is almost unanimous in the opinion that the architect’s ego is one of the causes of the lack of participatory processes. The professionals consider that architects are not open to including the end users in the design process, feel threatened by the innovation, and fear losing control over the project. On the other hand, a small percentage of Group A experienced this issue.

Another difficulty mentioned by most of the professionals from Group B and some from Group A is that participatory processes are time-consuming and costly. Also, 36% of Group B consider that there is a cultural issue. They state that participation is interpreted as community work and not as architecture, which is interpreted as an art and, therefore, is not included in the design process. Group B also stated that there are few participatory processes in architecture because there is no opportunity, as the end users are usually unknown. The professionals say that the communication is made with the promoter, and they do not ask for a participatory process to be made.

Some professionals from both groups listed the lack of consensus and the existence of conflicts as difficulties. They consider that if the negotiable aspects are unclear, it is difficult to manage powers, and conflicts arise.

The interviewees also listed the community's lack of skills. Some professionals think the community lacks technical knowledge, or experienced difficulties in the participants' perception of space.

A few professionals from both groups agree that the architects lack experience as facilitators of a participatory process, as this is not explored in the architect’s education.

A few professionals from both groups also raised the population's lack of interest and mobilisation. These professionals added that a lack of support (financial, for example) can contribute to this lack of interest. A few professionals from Group A mentioned having experienced difficulties managing large groups and a large amount of data.

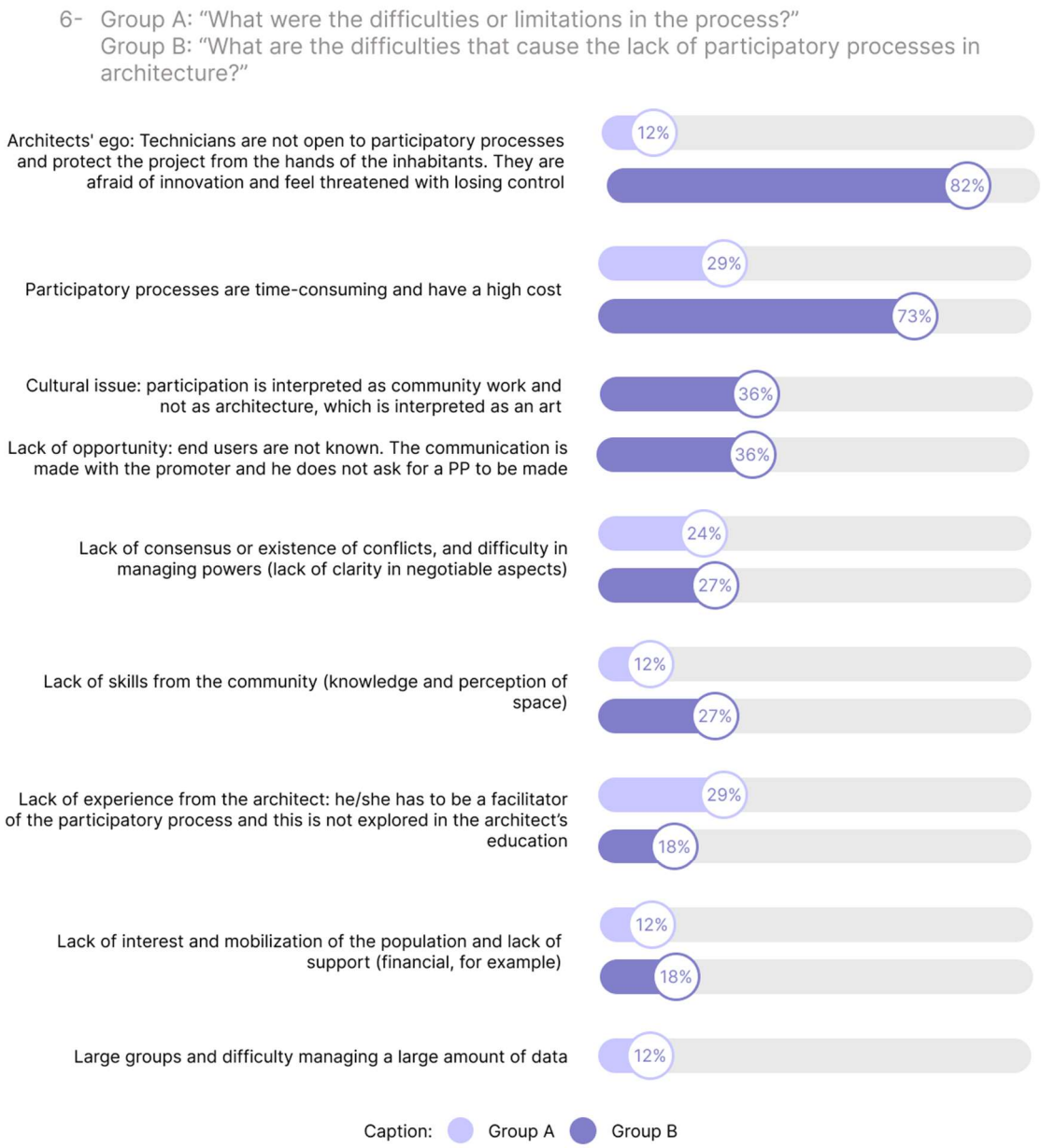


*Figure 26_Frequency of aspects mentioned by professionals (both groups) in response to an **open-ended question** about the difficulties inherent to participatory processes.*

Another open-ended question within the participation subject was about the interest of end users in participating. Group A was asked **"Did you feel that the community was interested in participating?"**, and to Group B was asked **"Do you think the community is interested in participating?"** (Figure 27). Most of the professionals from both groups agree that people are interested, essentially when the project directly affects their lives, such as their houses or the places they frequent daily. According to them, inhabitants are also interested in participating when they feel they are heard and have influence. The professionals highlighted that participating through cooperatives or bottom-up initiatives are indicators of their interest. Opposing this view, a minor percentage of the interviewees consider that the community is not interested in participating for

different cultural reasons. The professionals stated that there is a lack of community mobilisation, people are not used to participating and think that their voice is not important. Nine per cent of Group B did not responded to this question.

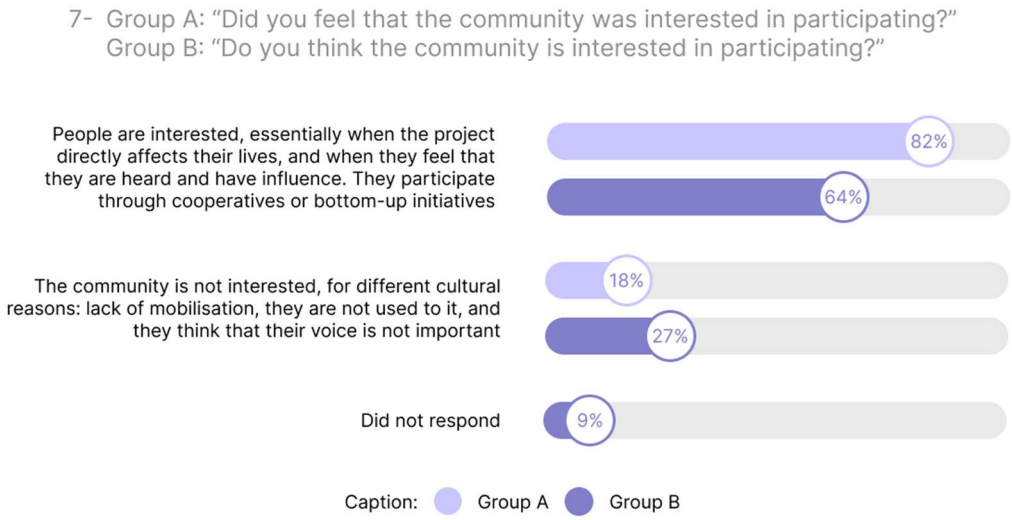


*Figure 27_Frequency of aspects mentioned by professionals (both groups) in response to an **open-ended question** about the community interest.*

An open-ended question was posed to Group A about the characteristics of the participants in the participatory projects they were involved in. Such question was **"How many people participated? Was the group diverse?"** (Figure 28). The diversity relates to different aspects such as age, profession, or spatial perception ability. The answers to this question were divided into two groups: the number of people who participated in a diverse group and those who participated in a group with similar characteristics. The most frequent answer was that up to 15 people participated, and the group was not diverse, as the participants had identical abilities in space perception. Some of the interviewees said that between 50 and 100 people participated, and it was a non-diverse group because the participants had close ages, and there was no diversity in the space perception, as they had no difficulties understanding the designs. Some other interviewees referred to groups between 200 and 300 people, with no diversity, and fewer said that 500 people in total participated, distributed in various sessions where the groups were similar in terms of ages and had some difficulties in understanding 2D drawings. Regarding diverse groups, a few professionals referred to groups between 25 and 30 people, where the participants were diverse and represented the different activities that take place in the city. Few other professionals said that between 50 and 100 people participated, referring to high cultural diversity, and others mentioned groups between 200 and 300 people and highlighted that the participation was made through a website and, therefore, there was a high

diversity. Finally, some of the respondents referred to thousands of participants with a high diversity for having also held an online participatory process.

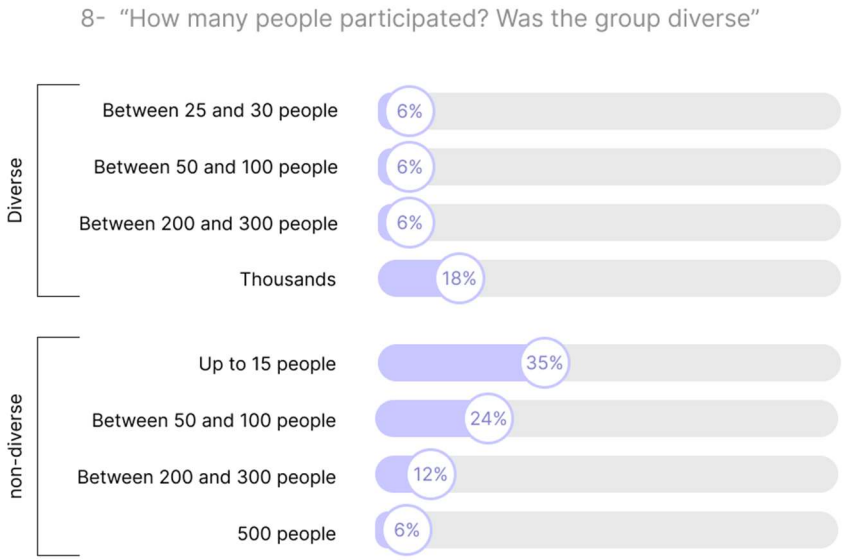


*Figure 28_Frequency of aspects mentioned by professionals (from group A) in response to an **open-ended question** about the number of people who participated in participatory processes carried out by them.*

To introduce the open-ended questions related to co-design, both groups were asked if **inhabitants should "put their hands on" to collaborate in producing design proposals** (Figure 29). Some professionals agree that inhabitants should collaborate in producing design proposals. However, there are more professionals of the opinion that inhabitants should not, because it is the architect's task. A considerable percentage of the interviewees from both groups did not answer this question.

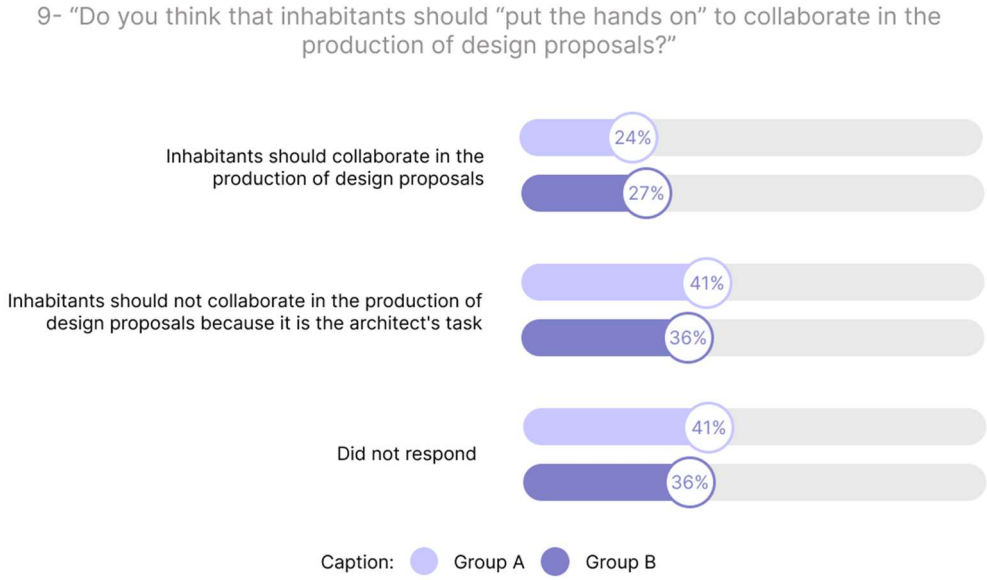


*Figure 29_Frequency of aspects mentioned by professionals (both groups) in response to an **open-ended question** about inhabitants' collaboration in the production of proposals.*

The open-ended question **“How can inhabitants collaborate in the design proposal?”** was also posed (Figure 30). From the answers gathered, the most mentioned method of collaboration was the 3D simulation (physical or digital). This method was cited by most of the professionals from Group B and a few professionals from Group A. Some of the interviewees also said that inhabitants can collaborate by ideating solutions and drawing maps collectively. A few professionals from Group A also mentioned they can make interventions in real projects. Although it was explained to the interviewees that the term “collaboration” meant the active involvement of participants in the production of proposals, some professionals from Group B answered this question with passive methods of participation. Such responses included the definition of requirements, voting on proposals prepared by architects, the use of online platforms to gather opinions from the citizens, and performing role-play activities. Many professionals did not respond to this question, especially from Group A, as they did not answer the previous question or responded that they disagreed with the inhabitant’s collaboration in the production of proposals.

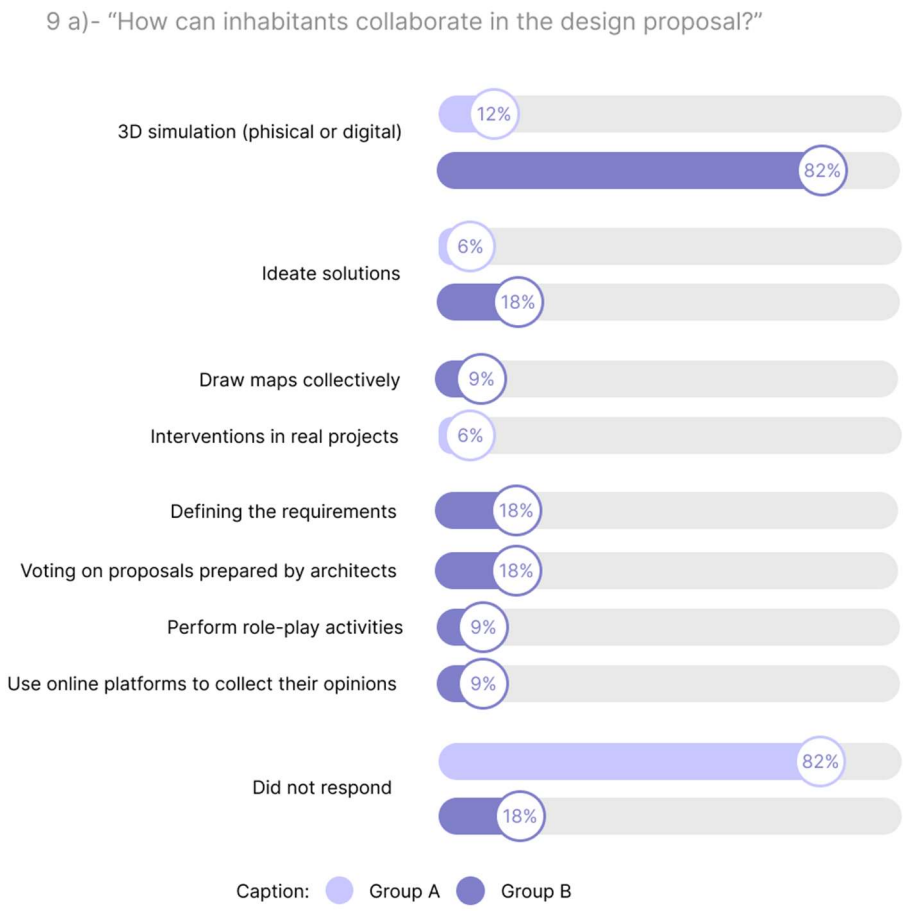


*Figure 30_Frequency of aspects mentioned by professionals (both groups) in response to an **open-ended question** about how inhabitants can collaborate.*

The open-ended question **“What are the limits of this collaboration?”** (Figure 31) was not posed to the same professionals who did not answer the previous question. The most frequent answer was

given by the professionals from Group B, who said that the limits of collaboration are technical limits that come from the architect's knowledge. They also noted that the limits are defined by the definition of roles for each party, and some of them referred to the solutions prepared by the architects. The context and budget were also limits cited by some professionals. The professionals from Group A who responded, referred to limits such as context, budget, and time constraints. A few professionals from this group said that there may be no limits. Many interviewees from Group A also did not respond to the question.

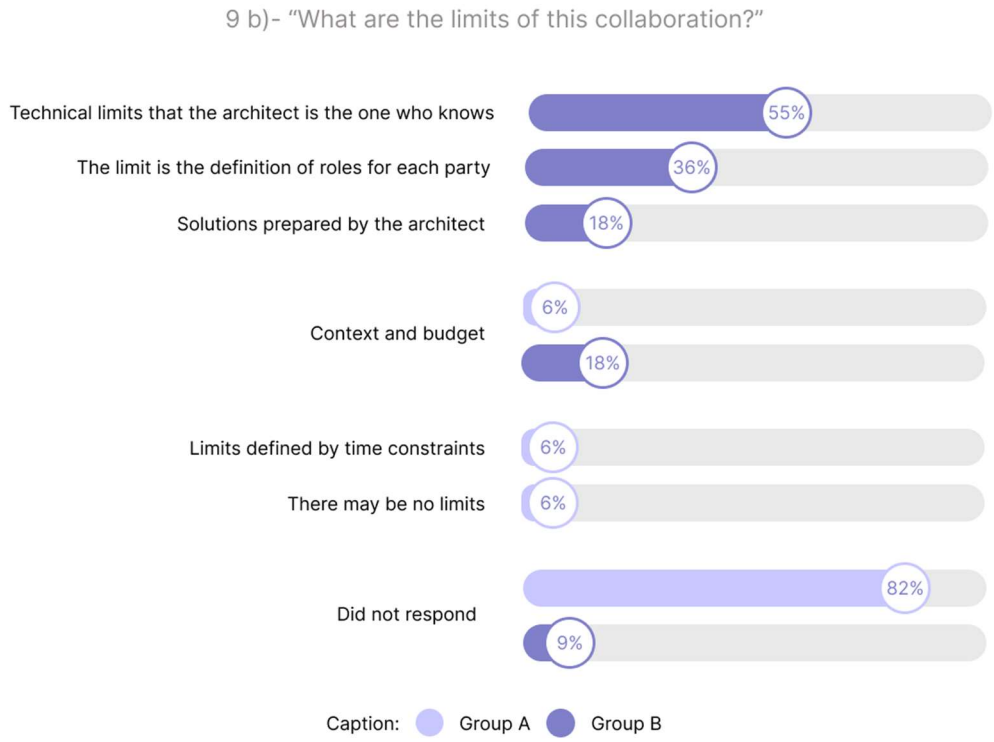


*Figure 31_Frequency of aspects mentioned by professionals (both groups) in response to an **open-ended question** about the limits of inhabitants' collaboration.*

The open-ended question **"What was presented to the participants and in what format?"** was posed to the interviewees from Group A (Figure 32) since they held a participatory or collaborative process. Most of them showed references in the form of photographs, videos and descriptive texts. Technical drawings were also often shown. Some professionals presented 3D physical models to support participation, and others provided maps. A 3D virtual environment for the participants to interact and create proposals was provided by a few professionals. A few professionals showed design proposals previously prepared by the architects. Some were represented in 3D and others in posters, with photos and technical drawings, from which inhabitants could vote. Fewer professionals provided other elements, such as hand drawings with base ideas to discuss, the space and materials for the participants to develop activities, and the budget was also shared.

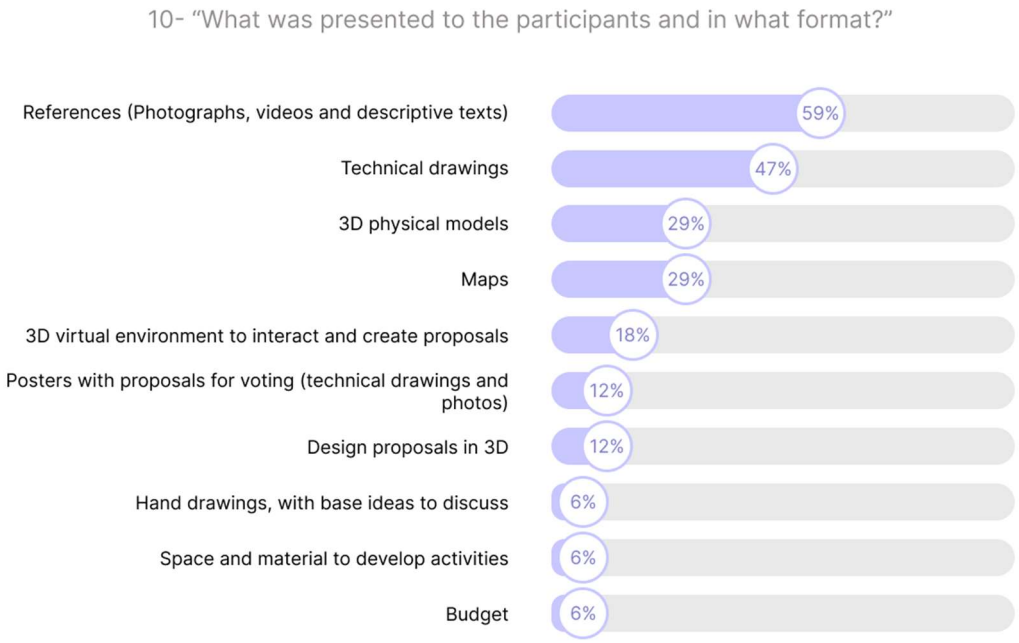


*Figure 32_Frequency of aspects mentioned by professionals (Group A) in response to an **open-ended question** about elements that they showed to the participants of the processes they held.*

About the activities performed by participants, Group A was asked the open-ended question **"What did the participants do?"** and Group B **"What do you consider to be the most effective methods for conducting a participatory process?"** (Figure 33). Group A mostly gave the participants the opportunity to communicate their preferences and give opinions, and choose (through voting) or comment on design options prepared by the architects. A few professionals from Group B also consider the latter an effective method for end-user participation. Some professionals from Group A also involved the end-users in giving and discussing ideas. The participants went on walking tours (to comment and give ideas at the intervention site) or discussed on a map (online or in person) by writing post-its and sticking stickers on the map. These activities were also mentioned by a few professionals from Group B. Another method carried out by Group A and referred to by Group B as an effective method, in their opinion, was to develop proposals. According to these professionals, the participants can use images or small three-dimensional elements such as Lego or clay to develop their proposals or even create physical models and experiment with full-size simulations. A few professionals from Group B suggested other methods for the participants to perform, such as drawing, playing games and using online platforms that could be used asynchronously. A few professionals from Group A also involved the participants in using digital tools to develop proposals in 3D virtual environments and in the construction process.

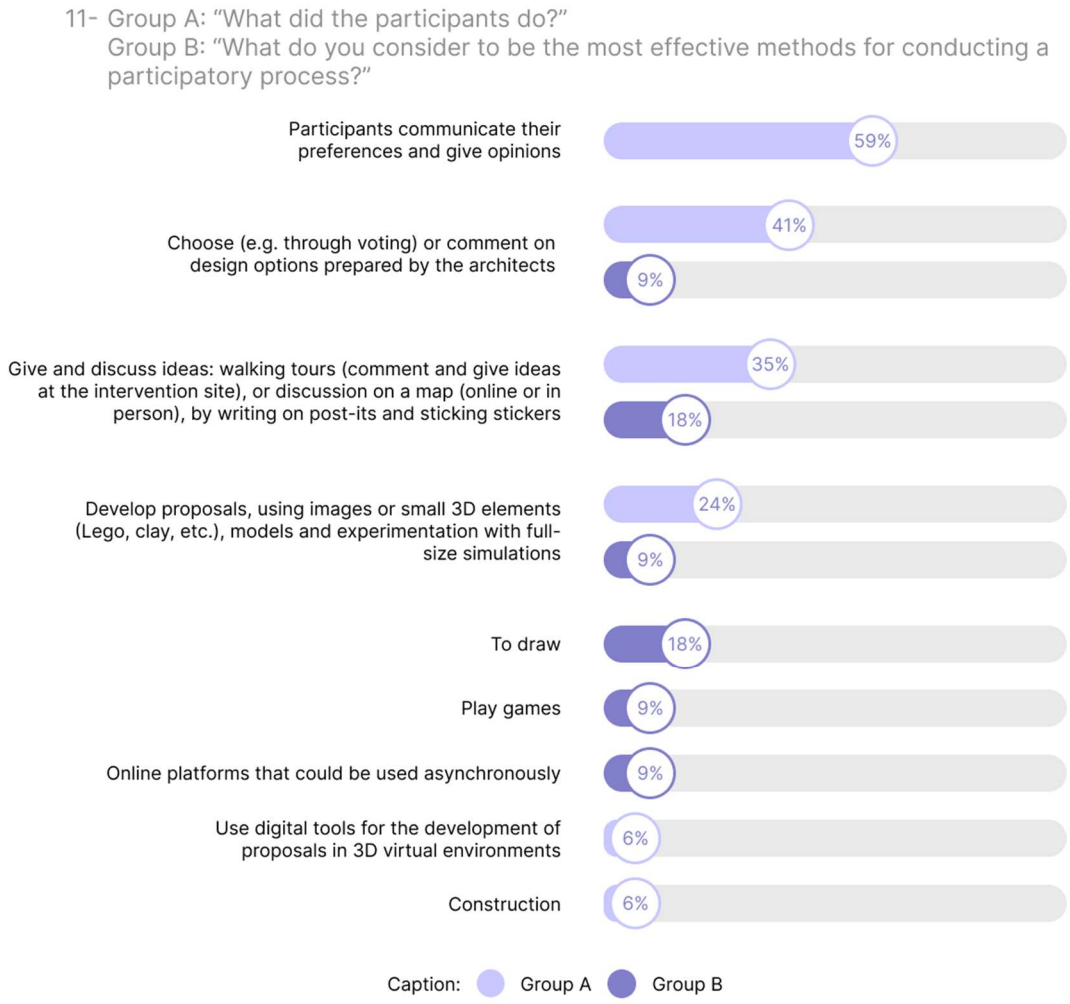


*Figure 33_Frequency of aspects mentioned by professionals (both groups) in response to an **open-ended** question about the methods inhabitants can use in participatory processes.*

As professionals from Group A referred to a specific case of a participatory process carried out by them, they were asked about the level of participation in which they involved the participants. To the open-ended question **"Do you consider it was a co-design or participation process?"** (Figure 34), almost half of them consider having involved the participants at the participation level, and stated that the participants only commented on or chose proposals made by the architects. A few answered that they involved participants at a co-creation level because participants didn't design a project, but created ideas. However, professionals added that the participants had no authority in the final decision, as the final decisions are taken by the owners in cases where the owners are not the end-users, such as in projects of public spaces or public facilities. Co-design was held by a few professionals, who involved participants in providing inputs and producing proposals. The interviewees also referred to a mixed process and stated there were moments of co-design, but it was not the entire process.

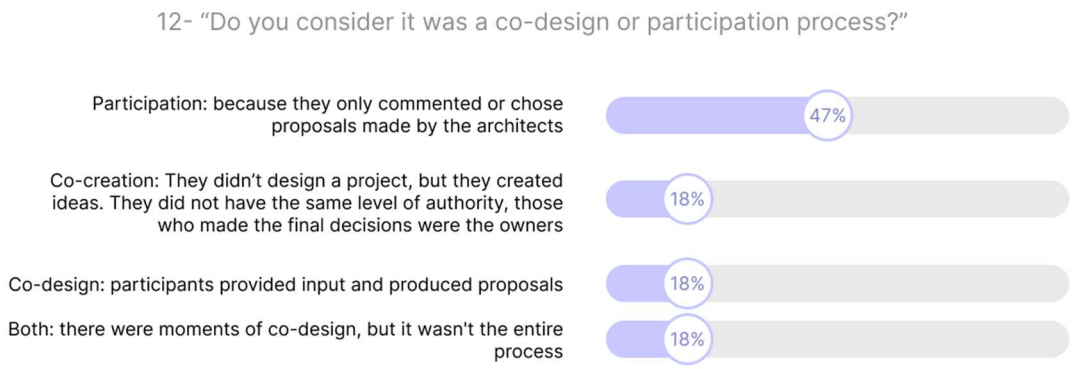


*Figure 34_Frequency of aspects mentioned by professionals (from Group A) in response to an **open-ended question** about the level of participation in the processes they carried out.*

As part of the questions related to digital technologies in participatory and co-design processes, both groups were asked **"How can digital technologies facilitate these processes?"** (Figure 35). With this open-ended question, multiple opinions from professionals were gathered , who mentioned many benefits but also a few barriers to using digital technologies in the participatory processes. The most mentioned benefit referred to by Group B was that digital technologies improve the perception of non-experts in architecture, as they enable visualisation from different viewpoints. They also mentioned the fact that technologies improve participatory processes by allowing the creation of simulations that show the consequences of the decisions taken. Some professionals from both groups highlight the importance of the internet in such processes, as it enables remote interaction and reaching large audiences. These professionals added that there are platforms that allow more than dialogue, such as, e.g., whiteboards. Group B also mentioned the contribution of digital technologies to time efficiency and motivation of the participants, as they are interactive and playful. Another benefit mentioned by both groups was that technologies help to manage large amounts of data and generate various possibilities, giving the example of systems to analyse patterns. Group A said that technologies can be used to gather information that helps to prepare for in-person workshops. Even so, a few professionals from Group B consider that technologies should be more integrated into the design process, as they support more than just gathering information. Other benefits of using digital technologies mentioned by a few professionals from Group A include monitoring the status of the process, the use of video and images to present references and the project, and the possibility of working in the same 3D environment. Although many benefits were mentioned, both groups also identified the disadvantages of using digital technologies in participatory processes. They stated that digital technologies are not fully inclusive and should not completely replace face-to-face interactions, as empathy is gained in person in informal moments. A few professionals from Group B added that technologies do not help, if the participants need to learn how to handle them to interact with the design process.

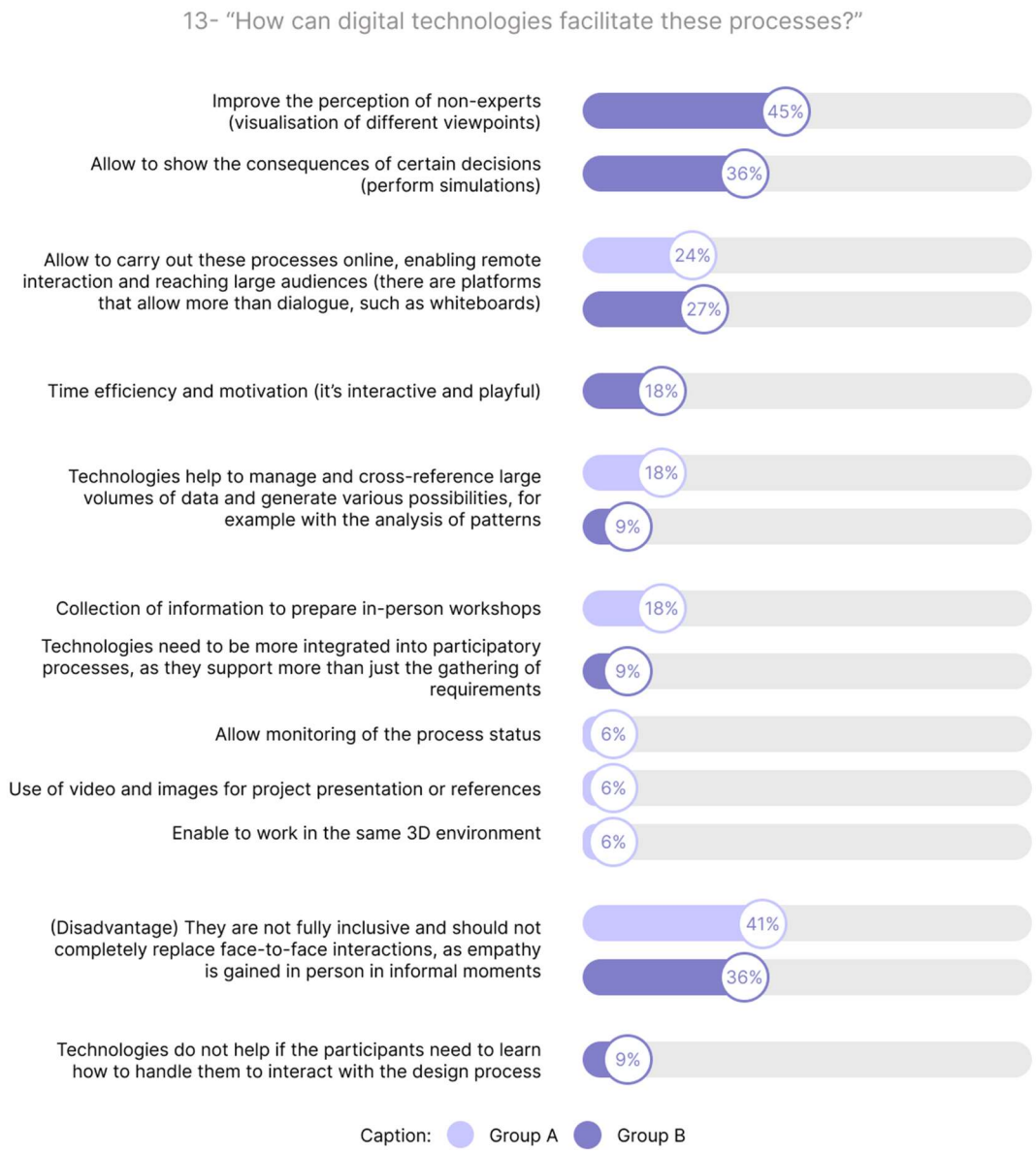


*Figure 35_Frequency of aspects mentioned by professionals (both groups) in response to an **open-ended question** about the digital technologies' influence on participatory processes.*

Group A was asked whether they used digital technologies in the process they were involved in. To the open-ended question **"Was any type of digital technology used?"** (Figure 36), A few interviewees said that participants interacted with digital technologies during the process. Some of the interviewees said they used websites, web maps and online interaction systems such as Miro. Other professionals reported that the participants used 3D virtual environments, Virtual Reality tools, online data, 3D printers and analysis tools. Some used digital technologies in a complementary way to support the presentation of PowerPoint or videos, and the architects used digital systems to create design proposals. As such, participants did not manage any digital tools. Some other professionals answered that they did not use digital technologies in the participatory process.

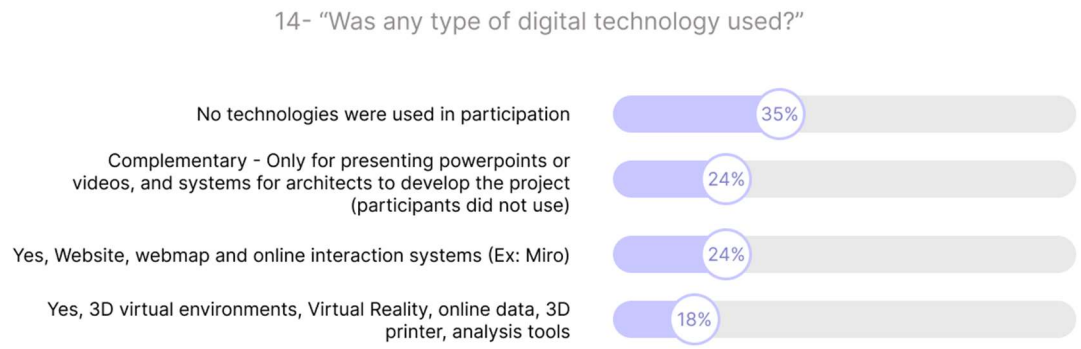


*Figure 36_Frequency of aspects mentioned by professionals (from Group A) in response to an **open-ended question** about the use of digital technologies in participatory processes they held.*

The following questions were asked to Group A as they experienced the influence digital technologies had or could have on the participatory processes they carried out. However, only about half of the interviewees from Group A answered most of the following questions.

The majority of Group A answered the open-ended question **"How do technologies influence the perception of space by non-professionals?"** (Figure 37) by saying that technologies allow for improving the perception of space by showing images of the project, such as 3D, Virtual Reality (VR) and Augmented Reality (AR). A few professionals added that with digital technologies, it is possible to create animations that simulate the activities included in the project. However, some of them said participants should not manage digital tools to create design proposals, as technical limitations can block creative thinking.

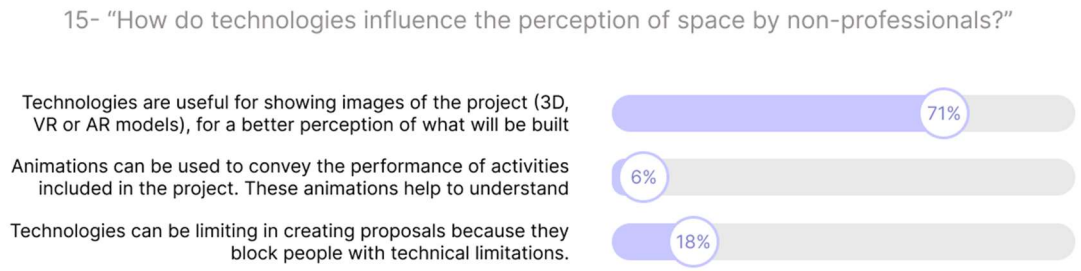


*Figure 37_Frequency of aspects mentioned by professionals (from Group A) in response to an **open-ended question** about the influence of digital technologies in the perception of space by non-professionals in architecture.*

The open-ended question **"How can digital technologies engage the community?"** was posed (Figure 38). Some interviewees said that the inhabitants' interest in participating is in social and political issues, and in the activities carried out, whether using technologies or not. Even so, the professionals stated that younger people are encouraged to participate because they are generally more connected to digital technologies. Besides, the interviewees consider that the interest is stimulated by the 3D visualisation and the entertainment and fun provided by digital technologies. Also, according to the professionals, participation can be encouraged through dissemination and documentation of the process.

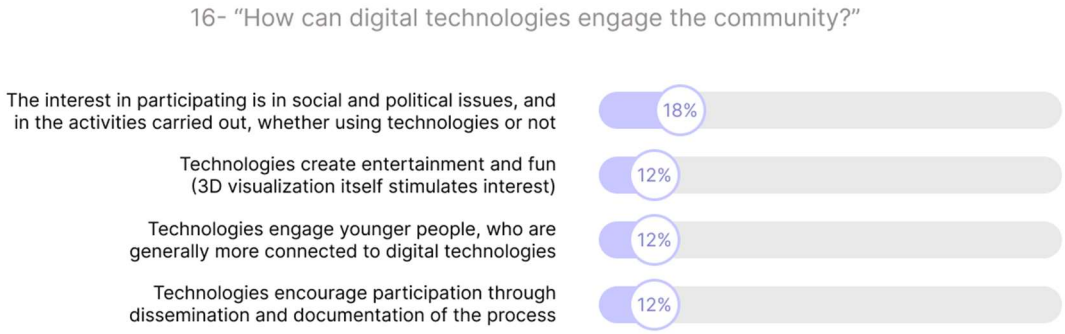


*Figure 38_Frequency of aspects mentioned by professionals (from Group A) in response to an **open-ended question** about the influence of digital technologies in engaging the community on participatory processes.*

To the open-ended question **"How can technologies balance the limitations of architecture regulations and the freedom of the community to design?"** (Figure 39), some of the professionals who responded suggested that a digital tool can inform or demonstrate limitations, such as a digital assistant. However, more professionals said that the architect is the one who should set the boundaries instead of technology. They state that the end-users can contribute with initial ideas according to their experiences, but the architect is the one responsible for creating the design based on end-users' ideas while dealing with regulatory restrictions.

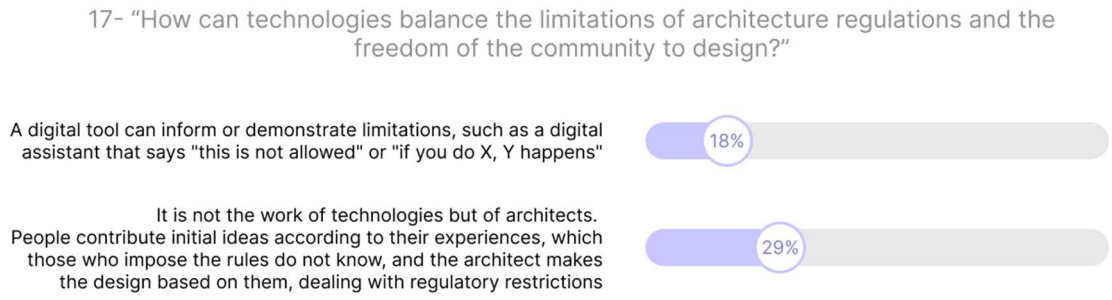


*Figure 39_Frequency of aspects mentioned by professionals (from Group A) in response to an **open-ended question** about the influence of digital technologies in balancing between limitations and freedom of the community to design.*

Regarding the open-ended question **"How can a group of people collaborate using the same digital tool simultaneously?"** (Figure 40), some professionals suggested that participants work in different project areas. Some professionals said the participants can individually create their designs and then comment or vote on each other's proposals. Another suggestion was to use systems like Miro and Zoom for the participants to communicate. A few professionals suggested that the participants can dialogue about the same project using the tool on a rotating basis, and also that they can use the same digital tool simultaneously if they participate through a website.

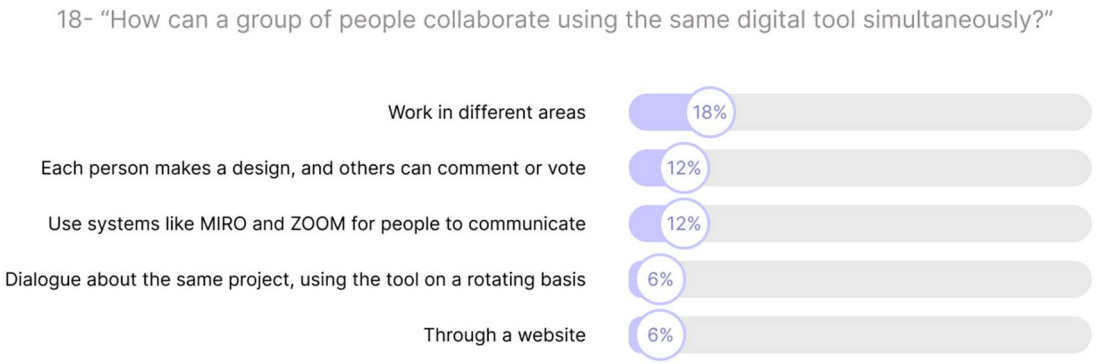


*Figure 40_Frequency of aspects mentioned by professionals (from Group A) in response to an **open-ended question** about the simultaneous use of a co-design tool.*

3.3.3 Discussion

The goal of these interviews with the professionals was to identify how participatory processes occur and could occur. Another goal was to gather their opinion about aspects such as the need for the inclusion of end-users in the design process and how digital technologies can support such an approach. Given the results of the interviews, it was identified that **there are few cases of participatory processes in collective housing**. Most of the professionals interviewed working with housing were from Portugal, and the ones who held participatory processes did so at a limited level of involvement. In other domains - such as urban design, public facilities, and related planning practices -, Portuguese professionals also do not involve end-users at a co-design level. Although a few foreign professionals carried out co-design processes, none of them were for housing.

Most professionals agree that housing should be customised, and the social sciences professionals emphasise that housing is an essential good and that customisation positively impacts the inhabitants' quality of life. The interviewees also highlight the inhabitants' satisfaction and appropriation regarding the house as the main **consequences of customisation**. Despite this, some professionals say that customisation should not compromise the cost and **flexibility of housing** so that it can adapt to new demands. A customised design can be affordable and does not hinder the dwellings' flexibility. According to Khalili-Araghi and Kolarevic (2018), customisation does not sacrifice efficiency and affordability if constraints are defined. The authors state these constraints can be standard predefined options that, when combined, allow for affordable customisation. Furthermore, approaches such as Open Building allow the end-users to define the interior of their houses and further change it independently of the building's envelope. As stated by Kendall and Teicher (2000), the infill may be determined or altered for each household or tenant without affecting the Support (or base building). The flexibility mentioned by the professionals relates more to construction systems that allow houses to be reconfigured in the future than to customisation during the initial design phase. Therefore, a

house can be customised at the initial design phase with the inhabitant's participation, and still be flexible for future changes, depending on the construction system used.

The participation of end-users in the design process is considered essential by most of the professionals interviewed for the customisation of houses. They refer to benefits such as the end-user satisfaction and empowerment of society. Despite such benefits, the professionals state that participatory processes can only occur when the end users are known and reinforce the need for housing to be flexible to adapt to the variety of end-users' needs. The respondents recognise the **lack of architects' openness as one of the main reasons that inhibit the development of participatory processes in architecture.** They also mentioned that these processes are time-consuming and that there is a lack of opportunity to practice them for various reasons, such as e.g., the unknown end-users. According to this opinion, Linden et al., (2018) say that architects often work for a general and abstract audience without considering the diversity of end-users. The authors state that architects use their own experience and values to make decisions about the design, shaping the end-user to their image.

The professionals who carried out participatory processes mentioned the **lack of architects' skills as facilitators.** As Marschall (1998) says, this happens because participation is not explored in the architect's education. On the other hand, Rachel Luck (2007) states that the learning process of communication with end-users is made through the practice and observation of other more experienced architects. The risk of conflict (for lack of consensus or the difficulty in managing powers) and frustration when participation expectations are not met were also referred to in the interviews as difficulties that inhibit participatory processes. Munster et al., (2017) state that the lack of transparency can cause such disagreements, as the goals should be clear and all the participants must have the same understanding of them. The professionals consider that, to deal with a group of people in a participatory process, the architect must have a structured process with a clear definition of the goals and each party's roles. They also say that architects must know how to talk to participants and be aware of their skills. Accordingly, Luck (2007) refers that clear communication is paramount in the architect's performance as a facilitator in participatory processes.

Another aspect mentioned during the interviews was **the lack of skills and knowledge from the end-users.** According to Marschall (1998), this leads to a gap in communication between architects and end-users. Munster et al., (2017) also state that participants lack an understanding of technical drawings, and it is difficult to communicate complex design issues to non-specialists. Marschall proposes solutions such as the architect as a facilitator must understand the participants' needs and transfer knowledge, to overcome the communication gap and provide them with a basis for making informed decisions. The author also argues that some level of standardisation does not conflict with

community participation, and provides a way to protect cost efficiency, quality standards and time delivery.

Although it was not mentioned very often, the **lack of interest from the community** was also addressed as a limitation. However, when asked, the majority of the interviewees said that the community have an interest in participating, highlighting that people are mainly interested when they feel they are heard and when the project directly affects their lives. In the field of housing, this interest is enhanced since, according to Yavari et al., (2015), (and as mentioned by social science professionals), housing is an essential good that affects the lives and well-being of the people who live there. Therefore, inhabitants have a greater interest in shaping their living environments than other public spaces.

As mentioned before, although the professionals support participation, they are reluctant to let end-users create design proposals, arguing that this is the architect's task and that the community does not have the knowledge to do so. They usually involve inhabitants at the participation level, and the **limits of collaboration** mentioned by the interviewees are mainly related to the definition of roles. They argue that the architect should prepare the design proposals, and the inhabitants can comment and make choices within the constraints defined by the architect. Accordingly, Linden et al., (2018) say that architects consider themselves the representatives of end-users' needs towards other stakeholders. The author adds that they care about the quality of spaces for the benefit of end-users and feel responsible for providing what they do not know due to inexperience. Architects consider that they must present alternatives that inhabitants are not aware of, or do not know they want, to add value to what is requested.

The professionals interviewed mostly presented references and technical drawings to the participants in the processes they held. Such references serve not only to illustrate design proposals with examples but also to **present possibilities and give ideas to participants** to encourage discussion, even if these are not elements for the inhabitants to work collaboratively. Even so, the foreign professionals interviewed, especially from group A, are more open to including end users through **collaborative activities for the creation of ideas and solutions**. This result was expected, as they were the ones who carried out collaborative processes with end-users. The **participation methods** (used by most of the professionals from group A and mentioned by the professionals from group B) mainly involved gathering opinions from the participants, defining requirements, and choosing from proposals made by architects. However, some professionals also referred to collaboration activities such as discussing ideas with maps, stickers, and post-its, and they mainly referred to making simulations and experimentation with 3D elements.

It was also observed that **digital technologies are still little used in participatory processes**, especially for end users to produce their own proposals, as the professionals who used them did it

mainly to show references and design proposals or to gather information from the participants (e.g., through an online map). Even so, professionals highlight the **potential of using digital tools,** arguing that they improve the perception of space by non-specialists in architecture through the visualisation of different viewpoints and the possibility of simulating the consequences of the decisions made. Although the professionals consider that the possibilities and limitations should be provided by the architects, a few of them referred that a digital tool can assist inhabitants in better understanding regulatory possibilities and limitations. They suggested that a digital assistant could inform or show the consequences of their decisions. Such an approach was explored in the work of McLeish (2003), who proposed a tool with a computational design critic trained by architects to help inhabitants in the co-design of open buildings.

Such automation brings knowledge to non-architects, allowing them to make informed decisions, but also increases time efficiency which was also mentioned by the professionals. Accordingly, Kwiecinsky et al. (2017), highlight the benefit of using digital technologies regarding the possibility of modifying the design and obtaining real-time feedback. According to the authors, such a possibility allows for multiple project iterations and accelerates the design process by avoiding manual modelling and visualisations. Another benefit of using digital technologies is their potential to foster the participants' interest and engagement. The professionals said that 3D visualisation by itself is engaging and attracts younger people. Accordingly, it is reported in the literature that the 3D strong visualisation capabilities are interactive and playful and have the potential to make projects more exciting, contributing to the citizens' engagement (Münster *et al.*, 2017; Galassi, Petríková and Scacchi, 2021; Ng *et al.*, 2023).

The professionals also mentioned that the Internet makes it possible to reach a larger audience and work remotely in the same virtual environment. Some authors state that digital technologies allow for large-scale participation and overcome geographic barriers (Münster *et al.*, 2017; Stelzle and Noennig, 2019). On the other hand, the interviewees said that digital technologies do not bring benefits if they require to learn how to operate them, and should not fully replace face-to-face meetings as they are not fully inclusive. According to Galassi et al., (2021) traditional methods should not be fully replaced. Instead, the authors argue that a combination of both should be considered.

3.4 Interviews with Housing Cooperatives

Representatives of ten Portuguese institutions that promoted the design and construction of collective housing between 1970 and 2020 were interviewed. The interviews with housing cooperatives were conducted considering that these institutions represent the desire of their members to build housing and make decisions about their living environments. The interviews were done with cooperatives that

carried out processes in which their members were involved in defining the design of their houses at some stage. A residents' association of a neighbourhood rehabilitated for rehousing the community, involving the inhabitants in the process, was also interviewed. **These interviews aimed to identify how these institutions operate concerning the process of designing, building, and promoting housing and whether residents participate or express a willingness to participate in the design process of their houses**.

Although the questions were semi-structured, the script was flexible, with the possibility of adapting the interview to the circumstances (e.g., if a housing cooperative did not involve the inhabitants in the production of design proposals, questions were not asked about the methods of collaboration used).

3.4.1 Sample

Interviews were carried out with representatives of ten institutions: the National Federation of Economic Housing Cooperatives (Fenache), the residents' association of a Lisbon neighbourhood (Bairro Padre Cruz), and eight housing cooperatives (Habipenha, Ugtimo, Força de todos, Novacoop, Nossa Vila Nossa Casa (NVNC), Coophanjo, Coohabita and Chesetúbal). Some of these institutions no longer promote housing construction processes but continue to manage the buildings or neighbourhoods they built. In the case of cooperatives that have carried out more than one project, they were asked to respond about a specific project that represented how these processes usually occur in the institution.

The typologies of collective housing projects these institutions promote are single-house residential neighbourhoods and apartment buildings. Their areas of activity are Lisbon, Setúbal and Azores, and they operate mainly for middle-low classes.

Housing cooperatives and residents' associations across the Portuguese territory were contacted, and the ten interviewed were the ones who agreed to collaborate on the research.

Table 5 shows the context of the institutions interviewed, whose identification was replaced by a code (C1, C2 …). The **"Date"** column indicates the timeframe during which the process of promoting housing with the participation of future residents was carried out. The timeframe is categorised by decades. The **"Location"** column refers to the area of the country where the institution is based (Lisbon district, Setúbal district, and Autonomous Region of the Azores). The **"Typology"** column refers to the type of housing that was built (houses or apartments).

Table 5_Interviewed Housing Institutions context.

Institution	Date	Location	Typology
C1	-	Lisbon	Apartments
C2	2011-2020	Lisbon	Apartments
C3	1991-2000	Lisbon	Apartments
C4	1970-1980	Setúbal	Houses
C5	2011-2020	Lisbon	Apartments
C6	2011-2020	Azores	Houses
C7	1991-2000	Setúbal	Apartments
C8	2001-2010	Lisbon	Apartments
C9	2001-2010	Lisbon	Houses
C10	1991-2000	Setúbal	Apartments

C1 spoke in general about the functioning of associated cooperatives, so the "Date" does not apply in this case. Of the remaining institutions interviewed, one promoted a participation process in the 1970s to 1980s; three cooperatives talked about a process that occurred between 1991 and 2000, two between 2001 and 2010, and three between 2010 and 2020. Regarding "Location", six institutions are based in the Lisbon district, three in the Setúbal district and one in the autonomous region of the Azores. As for the "Typology", seven institutions built collective housing buildings (apartments), and three built neighbourhoods of single-family houses.

Cooperatives based in the district of Setúbal promoted projects in older periods (between 1970-1980 and 1991-2000). The cooperative in the Azores is one of the most recent ones, and the processes carried out in Lisbon are distributed over different decades. Projects of single-family houses, although fewer than the projects of apartments, were built at the three locations (Azores, Setúbal and Lisbon). In the Lisbon district, mainly apartments were built.

3.4.2 Results

Twelve open-ended questions were posed to the housing cooperatives or resident association representatives. The questions focused on the institution's functioning regarding housing promotion and the housing construction process. These questions included the phases of the design and construction process and the process of hiring an architectural office. Information about the institution was also gathered, such as the geographic location, the income levels, and the age range of the population for whom these cooperative build houses. Another group of questions related to the participation process were asked, including questions about the group's diversity and how they participated. Finally, questions were posed about the motivation and satisfaction of the inhabitants.

The first open-ended question posed was **"How does the process of constructing residential buildings work in the association/cooperative – who are involved and what are the phases?"** (Figure 41). The answers are grouped into four subjects: land acquisition, design definition, meetings with all the cooperative members, and the construction phase. The land acquisition subject did not apply to one institution (10%), as they carried out a refurbishment on an already existing housing

neighbourhood. Most cooperatives (70%) acquired the land (or it was given to them by the city council) before the members were registered in the cooperative, and only 20% said that the land was acquired after members registered.

Regarding the design definition, half of the cooperatives defined the project with the participation of their members. The other half did not involve the members in the design decisions. Some of them (20%) defined the design before the members were registered, while the others (30%) defined it after the members were registered, although without their participation.

Regarding meetings, 50% of the cooperatives held assemblies with the partners and, sometimes, with the architect, where they could give their opinion on a base project and make decisions by majority. Thirty per cent said assemblies were held to showcase the project (without the members' intervention in its definition) and to address more general matters such as housing allocation. Twenty per cent reported that no meetings were held with members.

Regarding the construction, most cooperatives (80%) involved inhabitants during the construction phase, where minor adjustments and finishing choices could be made.

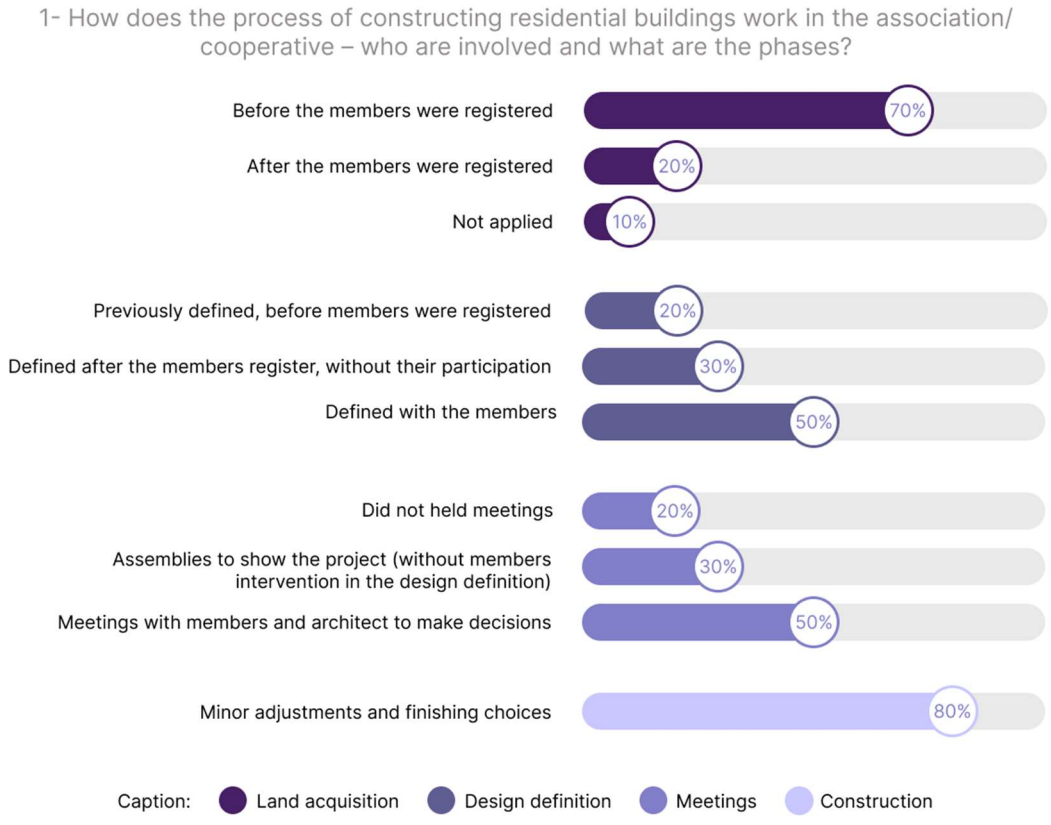


*Figure 41_Frequency of aspects mentioned by cooperatives' representatives in response to an **open-ended** question about their process of constructing residential buildings, with four subjects: land acquisition, design definition, meetings with all the cooperative members, and the construction phase.*

It was asked **whether the institutions hire the same architecture office** to carry out the project (Figure 42). This open-ended question did not apply to 20% of the institutions because only one project

was held. Some cooperatives usually hire the same office, and some answered that different offices are hired because they carry out consultations for each project, and the office that offers the best conditions is hired.



*Figure 42_Frequency of of aspects mentioned by cooperatives' representatives in response to an **open-ended question** about hiring the same architectural offices.*

To the open-ended question **"In which geographic areas have you worked?"** (Figure 43), the following Portuguese districts were mentioned: Lisbon (60%), Porto (10%), Faro (10%), Setúbal (40%), Aveiro (10%) and the Autonomous Region of Azores (10%). The interviewees also said that Lisbon is where there is the most demand.

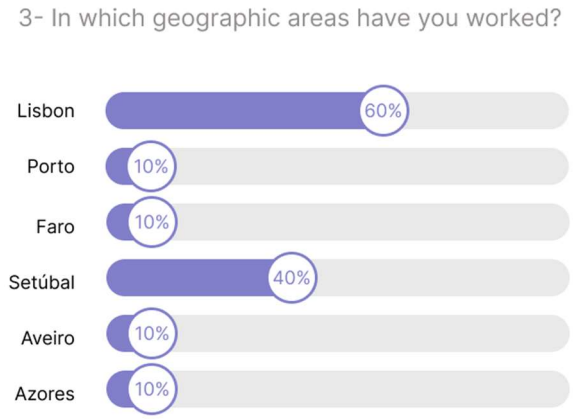


*Figure 43_Frequency of geographic areas mentioned by cooperatives' representatives in response to an **open-ended question** about where cooperatives have constructed (or are constructing) housing buildings.*

Regarding the open-ended question **"For which population economic levels have you worked?"** (Figure 44), almost all the cooperatives (90%) work with the lower-middle class. Additionally, some work with the middle class and a few cooperatives work also with the lower class.

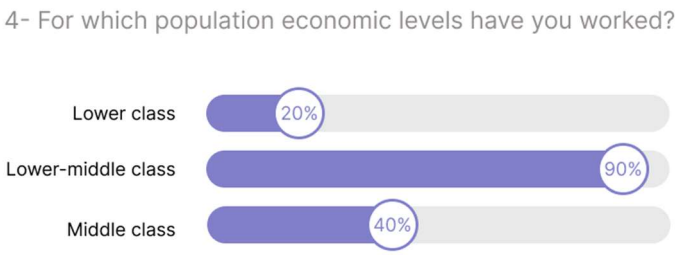


*Figure 44_Frequency of categories mentioned by cooperatives' representatives in response to an **open-ended question** about economic levels with which cooperatives work.*

The open-ended question **"What age range are the cooperative members?"** (Figure 45), generated heterogeneous and partially overlapping responses. One cooperative (10%) did not respond. Four cooperatives (40%) did not specify exact ages, and referred only to 'young couples'. In this study, 'young couples' is assumed to correspond to an age range between 20 and 40 years old. One cooperative (10%) reported a broad age range (25–60 years old), while two cooperatives (20%) indicated that their members are between 30 and 50 years old. Another cooperative (10%) reported an age range of 27–40 years, and one cooperative (10%) stated that its members are between 20 and 30 years old.

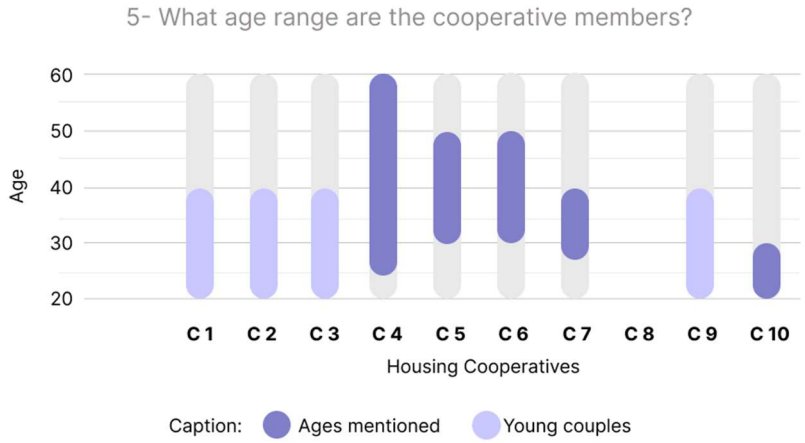


*Figure 45_Frequency of ages range mentioned by cooperatives' representatives in response to an **open-ended question** about cooperatives' members ages.*

Regarding the participation of the inhabitants in the housing design process, the open-ended question "**who encouraged the participation"** (Figure 46) was asked. In two cooperatives (20%), the inhabitants did not participate. On the other hand, the participatory processes are top-down initiatives, mostly driven by cooperatives (60%). The representatives said that although inhabitants were motivated by the participation, there were some who were shy and did not participate and others who did not even show up at the meetings. They added that people are only interested in their houses and not in participating in decisions about common spaces, which they also pay for.

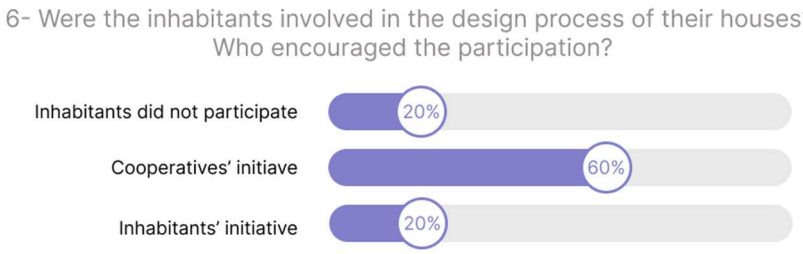


*Figure 46_Frequency of aspects mentioned by cooperatives' representatives in response to an **open-ended question** about the initiative of having a participatory process.*

The institutions were asked the open-ended question **"How diverse was the group of inhabitants who participated in the sessions in terms of age, profession, ability to understand the project, and connection with digital technologies?"** (Figure 47). Most respondents reported that there was little diversity in the group, while only 30% said the group was very diverse, although some people had difficulties perceiving an architectural project. The non-diverse groups had distinct characteristics. Forty percent said that although the professions were varied, the participants were young, had studies, and knew how to deal with digital technologies. On the other hand, in some cooperatives, most participants were individuals with low education, had no relationship with digital technologies, and had difficulties perceiving the project. A few cooperatives reported that the group consisted of elderly people, as they were the ones who had free time and were educated people.

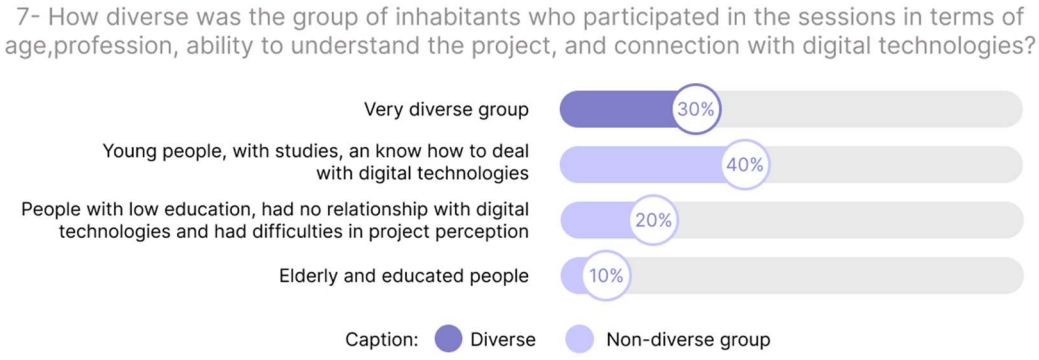


*Figure 47_Frequency of aspects mentioned by cooperatives' representatives in response to an **open-ended question** about the diversity of the inhabitants that participated.*

The representatives of the housing cooperatives were asked the open-ended question "**when inhabitants stepped into the design process"**. According to them, the inhabitants are involved in different phases of the process, including the preliminary design, final design, construction, and occupation phases. As shown in Figure 48, the occupation phase is where all the cooperatives involve their members by allowing them to choose the house by order of member registration number. The oldest members have priority in choosing the house, while the recently registered members are the last ones to choose.

In addition, the steps in which inhabitants are mostly involved are the definition of the initial requirements at the preliminary design phase and the choice of finishing materials during the construction phase. The inhabitants participate in the definition of requirements, usually in meetings with all the members. These meetings aim to collect information such as the housing typologies needed. The data collected during these meetings will inform the architect about the requirements to include in the design.

As mentioned, finishing materials are often defined during the construction phase, where a range is selected in advance for inhabitants to make their choices. The normal procedure that cooperatives adopt is to display samples at the cooperative's headquarters, or visits are made to the construction site where there is a model apartment for inhabitants to see the finishing materials applied.

Few cooperatives involve the inhabitants in defining the housing layout and choosing the finishing materials during the design phase. The inhabitants are also not usually involved in defining the housing layout during the construction phase. At this phase, only minor changes can be made.

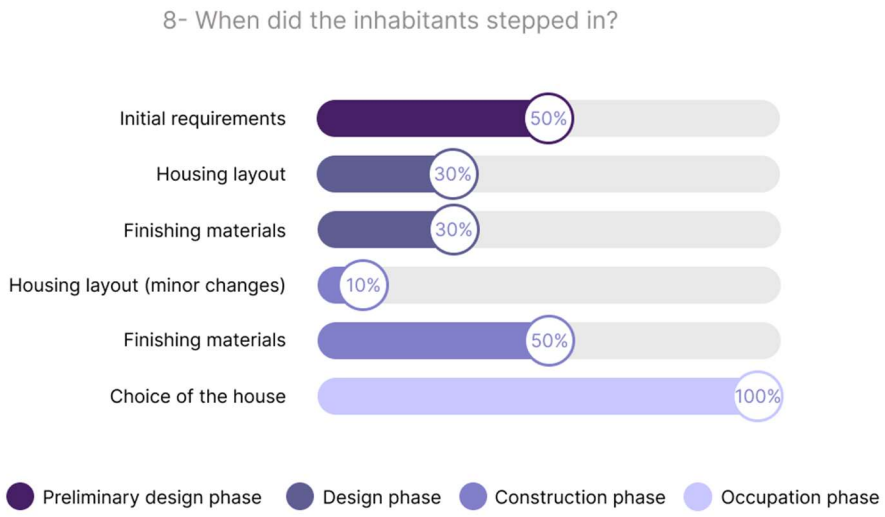


*Figure 48_Frequency of aspects mentioned by cooperatives' representatives in response to an **open-ended question** about the moments in which inhabitants stepped in during the different design phases.*

Regarding how the inhabitants participated, cooperatives were asked the open-ended question **"How did inhabitants participate? How was the participation session organised?"** (Figure 49). Two cooperatives did not respond (20%), as inhabitants did not participate. The answers to this question were given according to three topics: (1) how the inhabitants made their contribution, (2) how decisions were made, and (3) what was shown to the inhabitants to help them understand the project.

Regarding the contribution made by the inhabitants (1), the cooperative representatives stated that they contributed both orally and by filling out forms. The forms were used for the collection of information for the definition of requirements and to make choices of materials from the options available. The oral participation happened mostly in the meetings with all members, where they

commented on the project presented to them or voted on options given by the architect. Some cooperatives held individual meetings, where inhabitants made their requests or informed their choices orally. There were also cases in which both forms and oral participation were done in different phases of the process. The decisions (2) were made by the majority, in the voting sessions, and individually through the individual meetings or the filling of the forms. The cooperatives showed (3) mostly floorplans (technical or simplified) and made visits to the construction site. Additionally, a few cooperatives showed diagrams and images to the inhabitants. The representatives mentioned that inhabitants have some difficulty understanding the design through floorplans, however, when the design is verbally explained, they understand. Also, the visits to the construction site help to have a better understanding of the space.

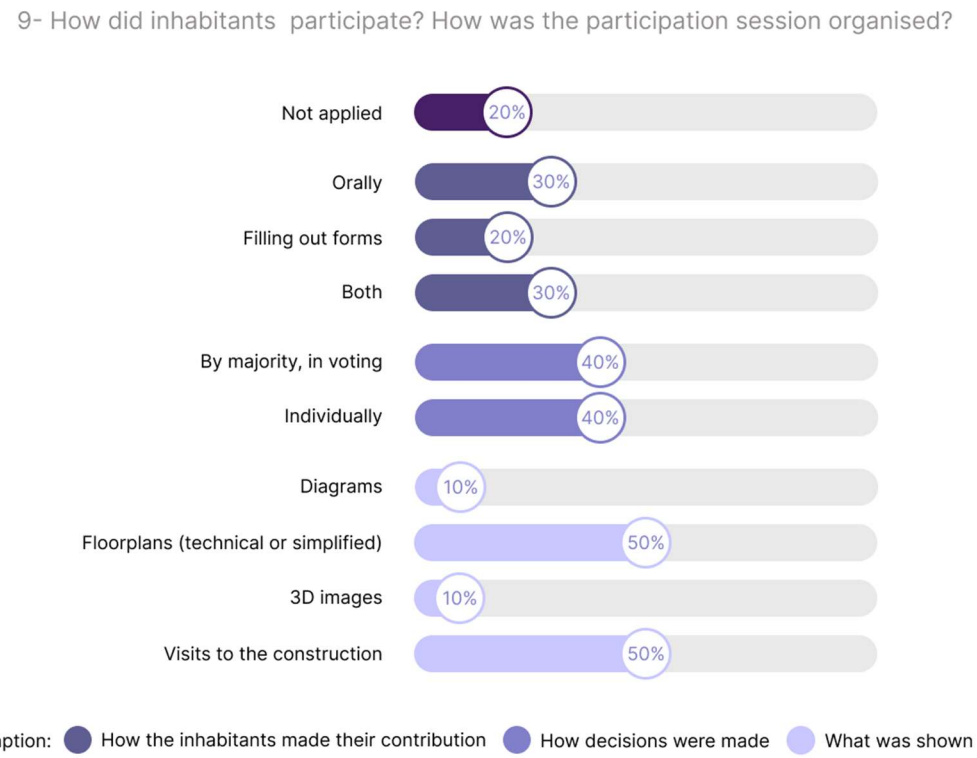


*Figure 49_Frequency of aspects mentioned by cooperatives' representatives in response to an **open-ended question** about ways inhabitants contributed according to three subjects: how they contributed, how decisions were made, and what was shown to them.*

To introduce the open-ended questions related to the inhabitants' satisfaction, the cooperative representatives were asked whether **the inhabitants were motivated to participate** (Figure 50). According to the cooperatives, inhabitants were motivated, especially when it came to the interior of houses. However, some mentioned that there are shy people. The interviewees also said that people are more motivated when a design is shown, as they can have a basis for giving their opinions. Ten percent of respondents did not answer.

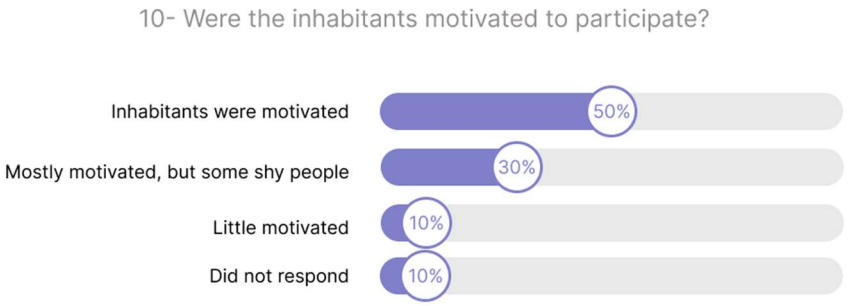


*Figure 50_Frequency of aspects mentioned by cooperatives' representatives in response to an **open-ended question** about their perception of the inhabitants' motivation to participate.*

The cooperatives were also asked if the inhabitants who participated mentioned having an interest in being more involved in the design phase through the open-ended question **"Did inhabitants express the opinion that they would have liked to have participated in the design definition?"** (Figure 51). The question did not apply to 40% of the interviewees because there were no participation sessions. According to cooperative representatives, people are not very interested in actively collaborating on the design, as most of them have not expressed a willingness to do it, although in some cases they commented on the project when it was shown to them. In other cases, people who intended to make changes expressed interest by mobilising themselves to ask for changes. However, this happened in a small percentage.

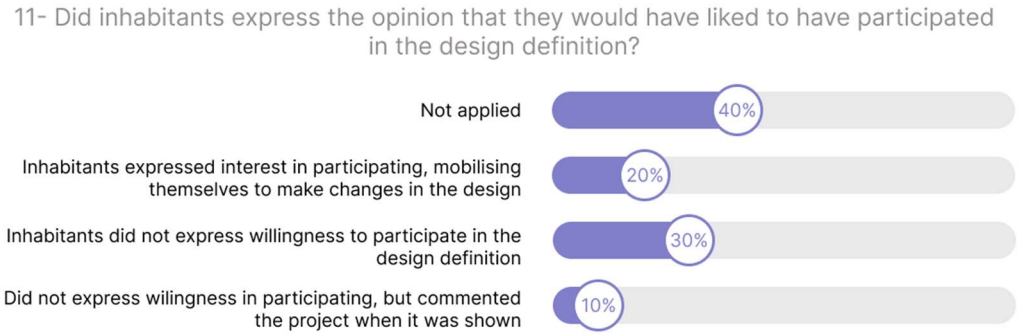


*Figure 51_Frequency of aspects mentioned by cooperatives' representatives in response to an **open-ended question** about their perception of inhabitants' willingness to participate in the design definition.*

Finally, to the open-ended question **"Do you consider the inhabitants were satisfied with the result?"** (Figure 52), most respondents said that the inhabitants were satisfied (80%). One interviewee said that, although they were initially satisfied, inhabitants made changes to the houses over time, and one said that some inhabitants were satisfied and others not so much, but over time they realised that the result brought better housing conditions than they had previously.

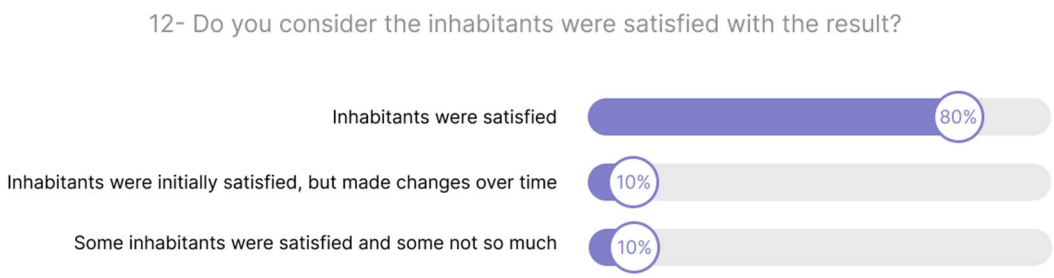


*Figure 52_Frequency of aspects mentioned by cooperatives' representatives in response to an **open-ended question** about their perception of inhabitant's satisfaction with the result.*

3.4.3 Discussion

The interviews with housing cooperatives aimed to identify how these institutions work and whether inhabitants participate or express a willingness to participate in the design process of their houses. It was identified that Portuguese housing cooperatives work with **middle/low-income people** who need housing at a lower cost. Despite having promoted housing in different periods, the cooperative representatives mentioned that they carried out processes with homogeneous groups of people, who were mostly young. Some of them reported that the participants were educated and had a relationship with digital technologies, while a few said that the group had lower education and did not have contact with digital technologies.

One relevant aspect mentioned is the **phases of the design process in which inhabitants are involved.** The results of the interviews showed that there are different phases in the processes of housing promotion and construction by cooperatives, ranging from land acquisition to the construction and occupation phase. The land acquisition is mostly done independently of the members' registration, which means they are not involved in the decision about the intervention site. Some cooperatives held meetings with the members and the architect during the design phase to define the initial requirements and, in some cases, for the inhabitants to participate in the design definition, such as in defining the housing layout and choosing finishing materials. However, inhabitants only comment on the project made by the architect and make decisions by majority, not being involved in the production of proposals. Also, in the construction phase, inhabitants can make minor adjustments and finishing choices. Given these findings, one can say that in the processes carried out by the housing cooperatives, the inhabitants are not much involved in the design but rather in the initial stages (such as the definition of requirements) or later stages, where minor changes or choices (such as material selection) that do not influence the overall layout of the dwellings can be made. Also, the house is chosen in order of the member number, which gives a false feeling of power of choice. Only the first member who chooses has total freedom to choose the house. The remaining members are conditioned to the available options.

It was observed that housing cooperatives are the ones who trigger the participation of inhabitants, and they mention that inhabitants are not very interested in being involved in the design definition. Most cooperatives said that there were shy people who did not participate, and others who did not even show up at the meetings. Cooperative representatives also said that people are only interested in their houses and not in participating in decisions about common spaces. This report is in line with the interviews with professionals, who say that **people are interested in participating when the project directly affects them**. Potential explanations for this lack of involvement are that inhabitants are shy to take bottom-up initiatives (as mentioned by the cooperatives) or are uncertain about their role in the discussion. It was also mentioned that people don't speak up because they do not know what they want, or they "just want a house". However, they can form a more informed opinion when a base project is shown. As such, inhabitants need to be better supported, and giving them the opportunity to collaborate on the design from the beginning overcomes this communication gap between members and representatives of the cooperatives. As stated by Luck (2007), the facilitator's performance encourages participation and influences participants' engagement. The author says that communication must be clear and with well-defined goals.

Another relevant aspect concerns **the way inhabitants participate**. Cooperatives involve inhabitants by filling out forms and giving opinions orally in meetings. Sometimes, decisions are made by the majority through voting on project proposals made by architects. Collective participation done orally in meetings does not guarantee everyone’s satisfaction, as shy people often do not speak out and accept what is said by others (Sanoff, 2008). Furthermore, the approach of choices made by the majority does not mean that a consensus has been reached, especially with large groups, which can cause frustration to those who do not agree with the decisions made. According to Henry Sanoff (2000), the notion of consensus refers to the dialogue and exchange of ideas concerning each individual’s concerns until an agreement has been reached in the search for a solution. Authors such as Marschall (1998) and Sanoff (2000) argue that the traditional voting system should be replaced by a process of consensus finding to avoid conflicts and frustration. From another perspective, especially on housing co-design processes, participation on a more individual basis has the potential to better meet each end user’s needs. However, individual participation, such as filling out forms, has been carried out in phases of the process that do not involve direct decisions about the layout of the houses, since this type of involvement is used to collect general information or choose finishing materials. This thesis suggests that inhabitants should be involved in the initial design decisions by collaborating, on an individual basis, in shaping the layout of their houses. This approach would better respond to each household's needs since each house is defined independently, thus eliminating the need for voting or consensus finding. By collaborating on the design definition and production, inhabitants have a greater feeling of satisfaction and ownership regarding their houses (Ammar, Hj Ali and Yusof, 2013). Besides,

making activities develop the inhabitants' creativity and allow them to identify and express their needs and desires (Brandt, Binder and Sanders, 2013).

3.5 Interviews with Inhabitants of Housing Cooperatives

These interviews with inhabitants of housing cooperatives were carried out with people who were the house's first tenants, as they were involved in some way in the design and construction process. Therefore, interviews were not carried out with people who had acquired the property later, through purchase from another tenant, as they did not participate in any phase of the design and construction process. **The goal was to collect information on their perspective about the process of participation they were involved in.** These interviews also sought to understand what aspects they would like to participate in, how non-specialists understand architecture and how they could easily interact with the design process.

These interviews were conducted in three phases, with semi-structured open-ended questions in the first two phases and with a flexible script that allowed the interview to be adapted to the circumstances (e.g. if an inhabitant did not participate in the design definition, no questions were asked about how they participated). Also, recognising that interviewees may not possess technical expertise in architecture, straightforward language accessible to all was used. In the third phase, closed-ended questions were asked, as the goal was to define the inhabitants' requirements for a digital tool and its user interface.

3.5.1 Sample

Twenty inhabitants of housing cooperatives were interviewed. The interviewees were gathered through a snowball sample method, in which the cooperative representatives were asked to invite the inhabitants to participate in the interviews. Those interested in participating in this study gave permission to the cooperative representative to provide their contact details so they could be contacted to schedule the interview.

Table 6 summarises the characteristics of the interviewees regarding demographic information and their relationship with the cooperative, as well as knowledge regarding architectural projects, and digital technologies. This information was intended to inform the profile of the potential users of the digital interface proposed, since they would be members of housing cooperatives. To maintain anonymity, their identification was replaced by a code (e.g. I1, I2, etc.). The information was systematised into categories.

The column **"Age"** refers to the current age range of the interviewees and is organised into three categories (25 to 45 years old, 50 to 69 years old, and ages over 70 years old, inclusive).

The **“Year”** refers to the year the inhabitant registered with the cooperative.

The column **“Age at the time of registration”** refers to the age of the inhabitants in the year they registered with the cooperative.

The **“Education”** column categorises three levels of education: up to 9th grade, compulsory education (up to 12th grade), and higher education.

“Previous contact with projects” indicates whether the interviewees had already had any contact with an architectural project or with elements representing them, such as floorplans. The “No” category means that they had never had contact before the date they joined the cooperative, and the “Yes” category indicates that they had already had contact (because they had already worked in the construction or another job in which they had contact with technical drawings, because they have family or friends who work with these elements, or because during their training they learned to read technical drawings).

The **“Profession/Education area”** column refers to the education area of the interviewee, the actual profession in cases where the interviewee did not follow a specific area, or their former profession in the case of interviewees who have already retired.

The **“Relationship with digital technologies”** column refers to four categories (very limited, limited, good, and very good). The “very limited” relationship with technologies means that the person deals very little with digital technologies in their daily lives (for example, they do not know how to use a computer or only use their cell phone to make calls). The interviews with these people were carried out in person. The “limited” relationship means the person interacts with digital technologies for simple tasks (such as taking photographs, writing messages, and accessing social networks). The interviews with these people were carried out in person or by telephone, and in cases where they were carried out online, they had help from third parties to access the Zoom session. A “good” relationship means that the person deals well with digital technologies in their daily life and knows how to use software, including those they need to use in their work, access the internet, regularly use email, etc. The “very good” relationship refers to people who, in addition to all the previously mentioned tasks, also use digital technologies for other leisure activities such as video games and online shopping, have robotic devices at home, use virtual assistants, have tried virtual reality devices or even have knowledge in the IT field.

The **“Cooperative”** column indicates which housing cooperative the inhabitants are members of.

Table 6_Interviewed inhabitants' characteristics

Inhabitant	Age	Year	Age at the time of registration	Education	Previous contact with projects	Profession / Education area	Relationship with digital technologies	Cooperative
I1	25-45	2020	24	12th grade	No	Administration	Good	NVNC
I2	25-45	2019	40	12th grade	No	Press officer	Good	NVNC
I3	25-45	2019	25	12th grade	No	Childcare assistant	Limited	NVNC
I4	25-45	2019	23	12th grade	Yes (*)	Cooking and pastry	Very good	NVNC
I5	25-45	2018	28	Higher education	Yes (**)	Environmental engineering	Good	NVNC
I6	25-45	2019	23	12th grade	No	Military	Very good	NVNC
I7	25-45	2018	30	12th grade	No	Hotel business	Limited	NVNC
I8	25-45	2018	41	Up to 9th grade	No	Waitress	Good	NVNC
I9	25-45	2012	35	Higher education	No	Law consultant	Very good	NovaCoop
I10	25-45	1998	22	Higher education	No	Teaching	Very good	CoophAnjo
I11	70+	1990	39	Up to 9th grade	Yes (***)	Industrial course: Locksmith	Very limited	Carriscoop
I12	50-69	2015	50	Up to 9th grade	Yes (***)	Metalworking industry	Limited	Novacoop
I13	50-69	2007	38	12th grade	No	Supermarket	Limited	Coohabita
I14	70+	1992	47	12th grade	No	Accounting	Very limited	UGtimo
I15	50-69	1994	27	Higher education	Yes (*)	Real estate consulting	Very good	UGtimo
I16	50-69	1990	24	Up to 9th grade	Yes (**)	Driver	Limited	Carriscoop
I17	70+	1978	30	12th grade	Yes (***)	Professor and Industrial course	Very limited	Chesetubal
I18	50-69	1986	34	Up to 9th grade	No	Driver	Limited	Carriscoop
I19	50-69	1986	31	12th grade	No	Phone operator	Very limited	Carriscoop
I20	70+	1998	54	Up to 9th grade	No	Commercial Manager	Very limited	NHC

* Know people who work in construction
** Work or have worked in construction
*** Work or have worked in the industry: production and assembly of pieces

Although neither the age nor the gender of respondents was controlled, they were collected for demographic context. Men and women between 25 and 77 years old were interviewed. Ten inhabitants are between 25 and 45 years old, six are between 50 and 69 years old, and four are aged 70 or over.

Five inhabitants registered with cooperatives between 1978 and 1990, four between 1991 and 2000, one between 2001 and 2010, and ten between 2010 and 2020.

Seventeen inhabitants were under 45 years old when they joined the cooperatives, and the remaining three were over 47 years old.

Six interviewees had education in the category up to the 9th grade, ten had up to the 12th grade, and four attended higher education.

Thirteen had never had contact with an architectural project or elements such as floorplans before joining the cooperative, and seven had already had contact. Of these seven, three work or have worked in construction or another job in which they have contact with technical drawings, two deal daily with

architects or people who work in construction, and two had contact with technical drawings during their training.

Five inhabitants have a very limited relationship with digital technologies, six have a limited relationship, four have a good relationship, and five have a very good relationship.

Eight respondents belong to the *Nossa Vila Nossa Casa* cooperative (*NVNC*), two belong to *NovaCoop*, one to *CoophAnjo*, four to *Carriscoop*, one to *Coohabita*, two to *UGtimo*, one to *Chesetúbal* and one to *Nova Habitação Cooperativa* (*NHC*).

Most inhabitants (17 of 20) were between 25 and 45 years old when they entered the cooperative. The remaining three joined the cooperatives after 47 years old. These did not join to have their first house: they already had their own house but wanted to move with lower price or acquire a second house to leave it to their children in the future.

Most younger inhabitants (25 to 45 years old) have a good or very good relationship with digital technologies, while most of the oldest (over 50 years old) have a limited or very limited relationship.

Most people with a 9th-grade education (five out of six) are older, yet half of the inhabitants over 50 have completed compulsory education. Most of the youngest (nine out of ten) completed compulsory education (up to the 12th year) or higher education.

More than half of those interviewed (13 out of 20) had never had contact with architectural projects. Most of those who had contact (five out of seven) are people over the age of 50 who work or previously worked in the real estate sector, construction, or parts production and assembly industries.

3.5.2 Results

Sixteen questions were posed to the inhabitants, divided into three phases. In the first phase, inhabitants were asked about the participation process in which they were involved. These open-ended questions included why the inhabitants joined the cooperative, when they did it, who participated, the phases of the design process they were involved in, how they participated, what was shown to them, and whether they had difficulties in understanding the design.

The second phase focused on open-ended questions related to the participants' satisfaction with the outcome of the design and construction of their houses, as well as the process that took place. Inhabitants were asked about their satisfaction with the outcome and the changes they would like to make to the housing design. They were also asked about their opinion on the influence of their contributions to the final design. Their opinions were also gathered on aspects they liked the most and what they would change in the participatory process regarding the contact with the architect, how to participate and the tools used.

The third and final phase of the interviews collected information about how a digital tool could help inhabitants participate more actively in defining their houses. This phase aimed to define aspects

of the tool, such as functionalities (design phases in which inhabitants would like to participate), types of visualisation and interaction, and devices where the tool could be used.

3.5.2.1 First phase: The occurred participation process

The main **reason inhabitants looked for a housing cooperative** to build their houses (Figure 53) was affordability. In addition to the affordability, inhabitants mentioned they wanted to move to a better house than the one they lived in. Some inhabitants were familiar with the housing cooperative and joined because they were satisfied with the cooperative's previous houses. A few respondents said they joined for the opportunity to participate in the decisions about their future house.

On this topic of participation, inhabitants were further asked **whether the opportunity to participate was a decisive factor for them to join a housing cooperative**. Besides the ones who mentioned participation as the reason to join, most of the respondents did not know they would have the opportunity to participate, and, therefore, it was not one of the reasons why they joined the cooperative. Although some inhabitants knew they would have this opportunity, they were not motivated by it.

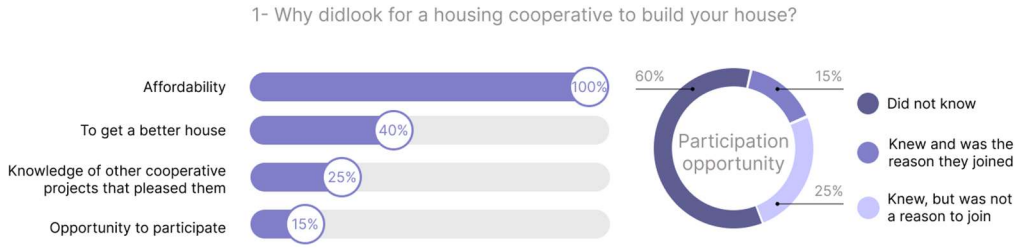


*Figure 53_Left: Frequency of aspects mentioned by inhabitants in response to an **open-ended question** about the reasons for them to look for a housing cooperative; Right: inhabitants' responses to the open-ended question if they knew they would have the opportunity to participate when joining the cooperative.*

Regarding the open-ended question "**when the project took place"** (Figure 54), 40% of the interviewees engaged in a process that occurred between 2011 and 2020. Fewer inhabitants were involved in projects in the decades of 1981 to 1990, and 1991 to 2000. Only one person was involved in a project between 1970 and 1980, and one between 2001 and 2010. Ten per cent of respondents could not answer because they joined the cooperative at a later phase and, thus, they did not participate in the decision-making about the houses' design nor know when it occurred.

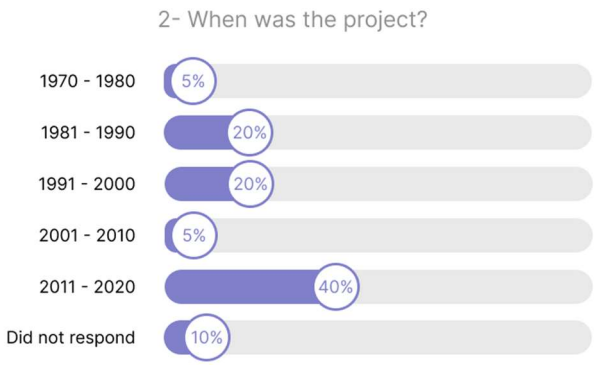


*Figure 54_Frequency of aspects mentioned by inhabitants in response to an **open-ended question** about the time frame of the process in which they were involved.*

Inhabitants were asked an open-ended question about **who participated in the participation sessions** (Figure 55). According to most of the interviewees, both inhabitants and the management of the cooperative were involved in defining the design. In addition to these participants, sometimes the architect was present at the participation sessions. Also, in fewer cases, the technical team (engineer, construction company, etc.), the manager of the bank and the presidents of the city council and parish council were present. Forty per cent of inhabitants were unable to answer because they joined the cooperative after the design was defined or because they were not given the opportunity to participate in the design definition.



*Figure 55_Frequency of aspects mentioned by inhabitants in response to an **open-ended question** about people who participated in the process they were involved in.*

Inhabitants were asked about **which parts of the project they gave their opinions or ideas on and how common spaces were defined** (Figure 56). The results of this open-ended question show that most of the inhabitants were involved in choosing the house (by order of member number, during housing allocation) and the finishing materials. Besides, some participated in the definition of the initial requirements and could make changes to the housing layout during the construction phase. Fewer had the opportunity to be involved in the definition of the housing layout during the design phase through voting on proposals made by the architects. None mentioned having participated in the definition of

the shared spaces. Forty per cent of the interviewees did not respond because they did not participate in defining the housing.

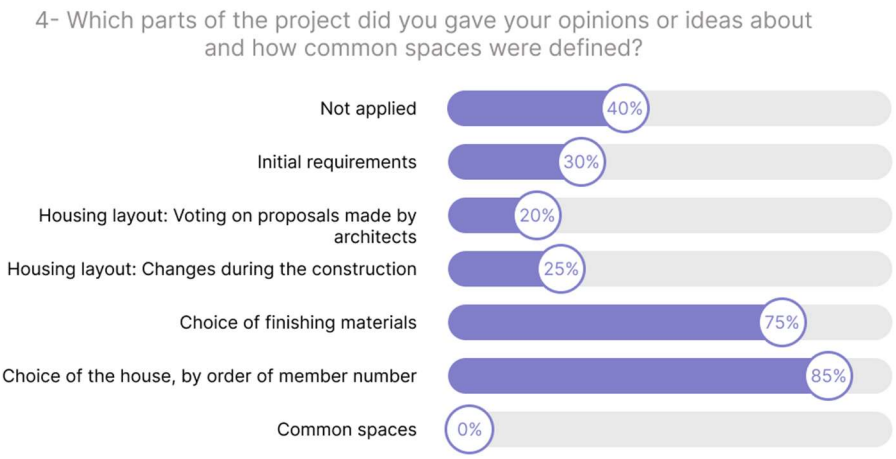


*Figure 56_Frequency of aspects mentioned by inhabitants in response to an **open-ended question** about the phases of the design process they participated.*

Regarding the open-ended question **"How did you participate?"** (Figure 57), Half of the interviewees had to make choices between limited options. These choices were made in some cases collectively (through oral voting in participatory sessions) and in other cases individually (via forms or in individual meetings). The same 40% that did not respond to the previous question did not respond to this question either, because they did not participate in the design definition.

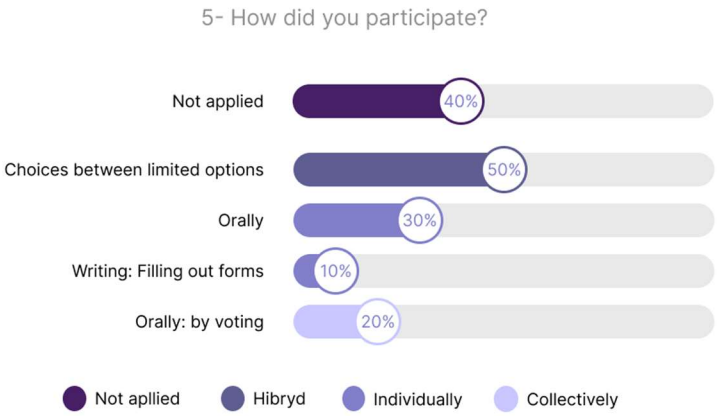


*Figure 57_Frequency of aspects mentioned by inhabitants in response to an **open-ended question** about the participation methods of the process they were involved in.*

Regarding the open-ended question about **what was shown to them to understand the project** (Figure 58), Different types of floorplans and 3D representations were shown, as well as samples of materials, and visits to the construction site were made to show a model apartment. More than one of these elements was often shown simultaneously. The detailed and simplified floorplans were the most shown elements, but also location plans and 3D images of the housing interior were shown often. Physical elements such as the 3D physical model of the building exterior and samples of materials were

available at the cooperative's headquarters for the inhabitants to see if they wanted. A smaller percentage of inhabitants have visited a model apartment at the construction site, and the 3D images of the building exterior were the least shown element. One person (5%) answered that they saw nothing besides the result, i.e., the built house.

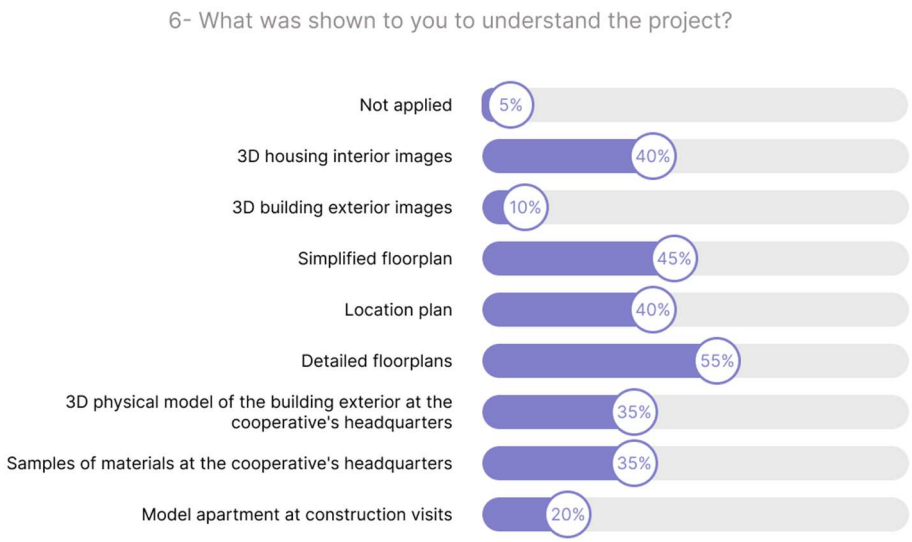


*Figure 58_Frequency of aspects mentioned by inhabitants in response to an **open-ended question** about what was shown to them to understand the project before the construction of houses was concluded.*

To the open-ended question **"Did you have difficulties understanding what was shown?"** (Figure 59) , one person (5%) reported having experienced difficulties for not having experience using technical drawings. Most of the inhabitants did not experience difficulties. The reasons mentioned by half of them were that the project was explained, and comparisons were made with examples they knew, but mostly the fact that the 3D images shown helped them understand the design. They were also asked if they would have been able to understand the design if these images had not been shown. Half replied that they would not understand, and the other half said that it would not be as immediate, but they would understand, although these are inhabitants' subjective perceptions. One respondent did not respond (5%).

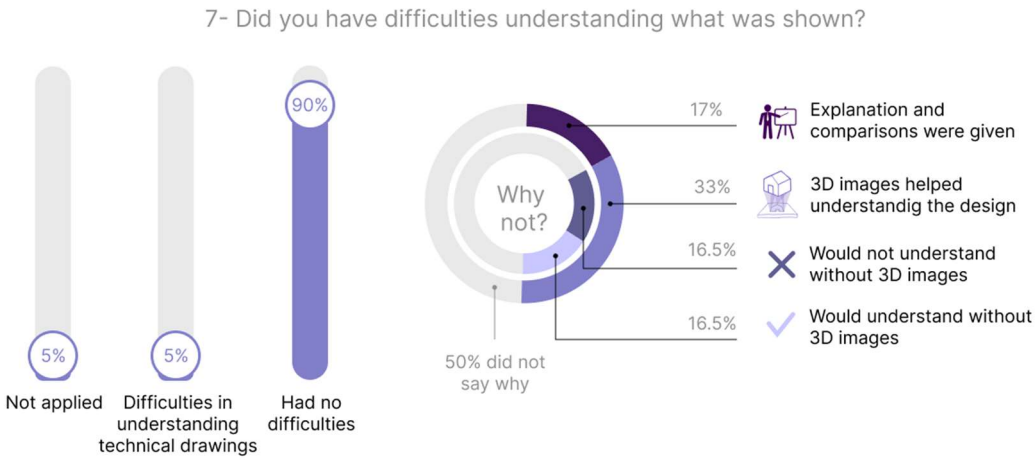


*Figure 59_Left: Inhabitants' answers to the **open-ended question** about if they felt difficulties in understanding the project through what was shown to them; Right: Frequency of aspects mentioned by inhabitants in response to an open-ended question about the reasons for not having difficulties understanding the project.*

Inhabitants were also asked whether there were **differences between their initial perception of the house design and the built result** (Figure 60). To this open-ended question, most of the inhabitants responded that there were no differences between the design and the built house, and only 10% responded that there were differences since the house appeared larger in the floorplan than what was built. Forty-five per cent of respondents could not answer because the construction of the houses had not been completed at the time of the interview or because they had not seen the design and, therefore, had no means to compare it with the built house.

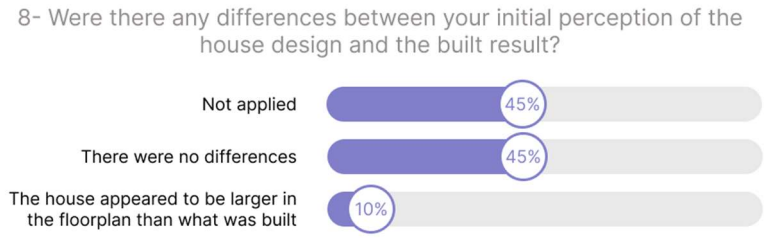


*Figure 60_Frequency of inhabitants' responses to an **open-ended question** about the differences they felt between the house design and the built result.*

3.5.2.2 Second phase: Inhabitants' satisfaction with the participatory process and result of the housing design

The second phase of the interviews, which was dedicated to collecting information about the inhabitants' satisfaction, started by posing an open-ended question regarding **their satisfaction with the result of the housing design and whether it was identical to what they expected** (Figure 61). The inhabitants were mostly satisfied with the result of the design. Some of them mentioned it was identical to what they expected, and some added that the result exceeded their expectations. Ten per cent said they were not satisfied, nor was it similar to what they expected. These were the same people

who, in the previous question, had mentioned that the built house seemed smaller than they expected when they saw the floorplan.

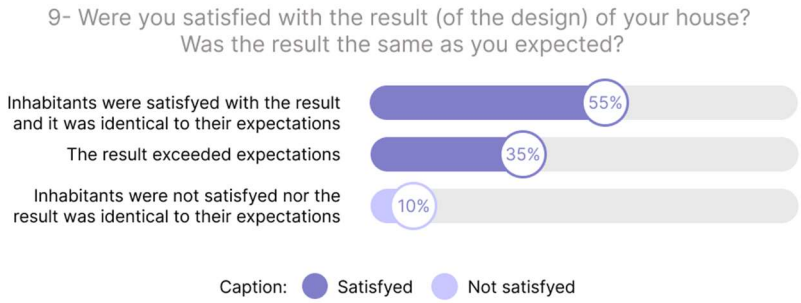


*Figure 61_Frequency of inhabitants' responses to an **open-ended question** about their satisfaction with the design result.*

Inhabitants were asked whether they think their participation influenced the result. Those who had the opportunity to participate were asked the open-ended question **"Do you think that, if you had not participated, the result would have been the same?"** and those who did not participate were asked the open-ended question **"Do you think that, if you had participated, the result would have been the same?"** (Figure 62). Most of the inhabitants who have not participated believe that if they had, the result would not be the same because they would have suggested changes to make the house better suited to their needs. On the other hand, some of them believe that the result would be the same, stating that they would be just one more opinion among many that would not make a difference or that their opinion wouldn't be valuable because they do not understand architecture. Regarding the inhabitants who participated, some of them said that the result would be the same, as the regulations were tight, and there was no room to accommodate their requests. Ten per cent of respondents did not respond.

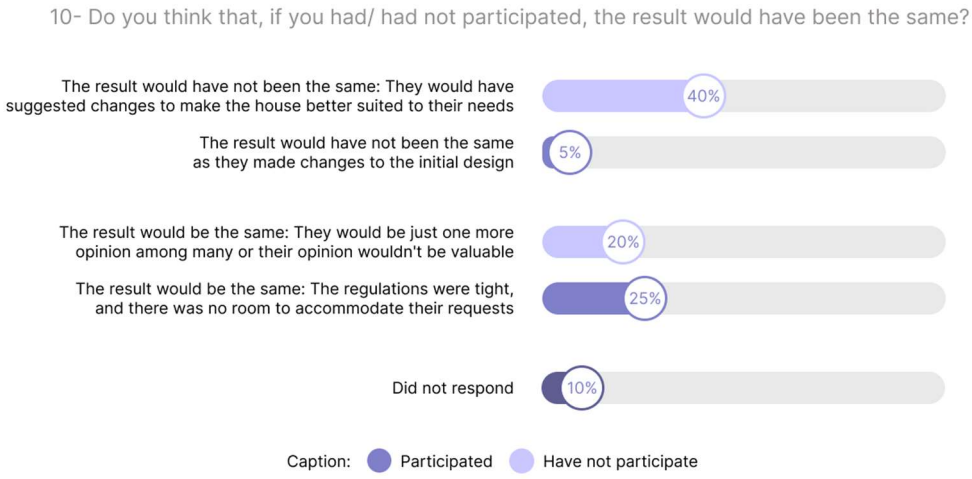


*Figure 62_Frequency of aspects mentioned by inhabitants in response to an **open-ended question** about their perception of the influence of their contributions in the design result.*

The inhabitants were asked the open-ended question about **what they would change** (Figure 63). Some of them responded they would change the finishings, the interior housing layout and would like

to have larger areas. Some inhabitants would also like to have balconies and make changes to the windows. Fewer said they would not change anything. Fifteen per cent did not answer this question.

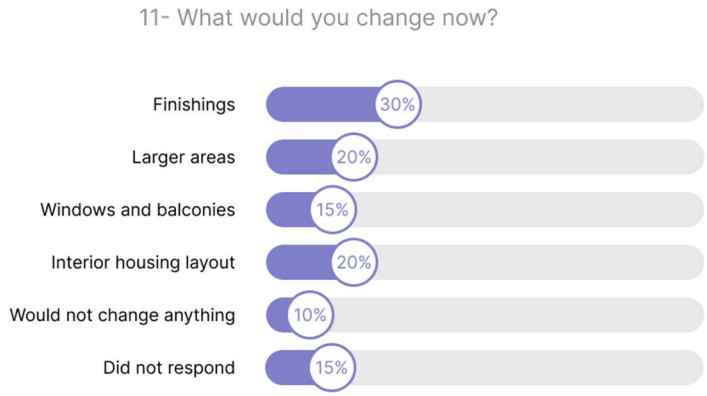


*Figure 63_Frequency of aspects of the design outcome mentioned by inhabitants in response to an **open-ended question** about what they would change.*

Regarding the open-ended question about the **aspect of the process they enjoyed the most** (Figure 64), having contact with the design is what stands out. The inhabitants who answered this were not only the ones who made decisions about the project but also those to whom the design was shown even though they did not participate in the design definition. It was mentioned that having an active intervention gave the feeling of having a customised house. Also, they said that seeing the design allowed them to visualise their future house with something more tangible than just words. The inhabitants were also satisfied with the cooperative's transparency, keeping them informed about the process (they were informed about the various phases, such as the land acquisition process, the foreseen number of houses to be constructed, the rules for allocating housing to their members and the status of the licensing process at the city council) and the union between members. Some inhabitants expressed their happiness with the moment the house was ready. Twenty per cent of the inhabitants did not respond this question.

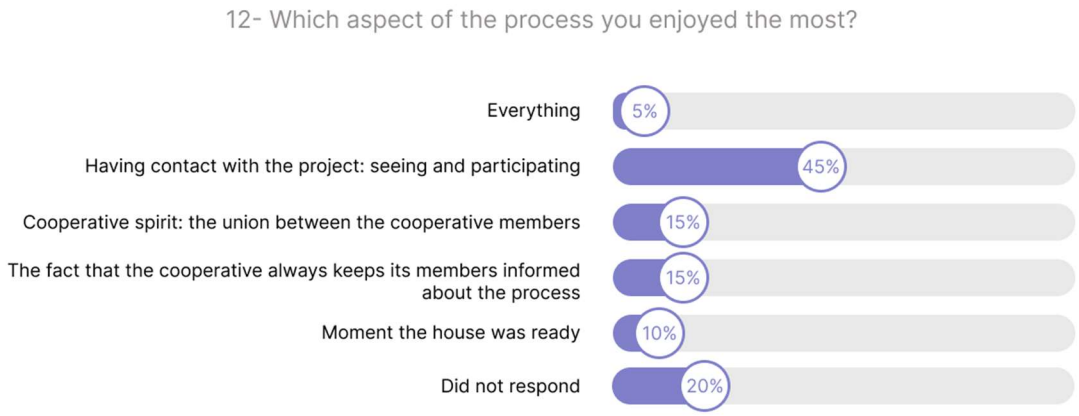


*Figure 64_Frequency of aspects of the process mentioned by inhabitants in response to an **open-ended question** about what they enjoyed the most.*

The responses to the open-ended question **"What would you like to have been different in the process regarding your relationship with the designer?"** (Figure 65) were divided into two groups: those who had contacted one or more times with the designer (25%) and those who had no contact at all (65%). Most of the inhabitants interviewed liked or would like to have contact with the designer to participate actively in the design definition. Only 20% had no contact with the designer and would not change this. Still, 10% of those who had contact with the designer would like to have been more frequent and effective. These people were those who participated in the process, but not in the design definition phase. Two people (10%) did not answer this question.

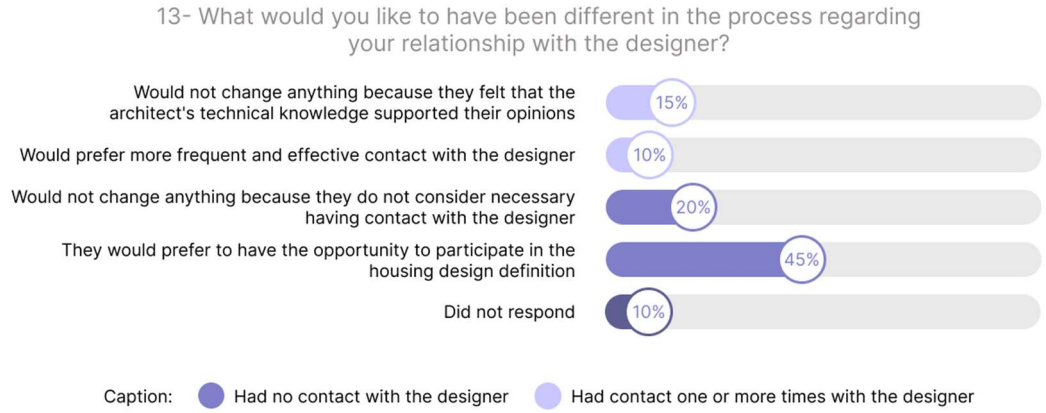


*Figure 65_Frequency of aspects mentioned by inhabitants in response to an **open-ended question** about the contact they had with the designer.*

Regarding the open-ended question **"What would you like to have been different about the process regarding the number of times you spoke with responsible for the project"** (Figure 66), 60% answered that they would not change anything, and 20% said they would like the process to have been faster and more collaborative. Twenty per cent of the interviewees did not respond to this question.

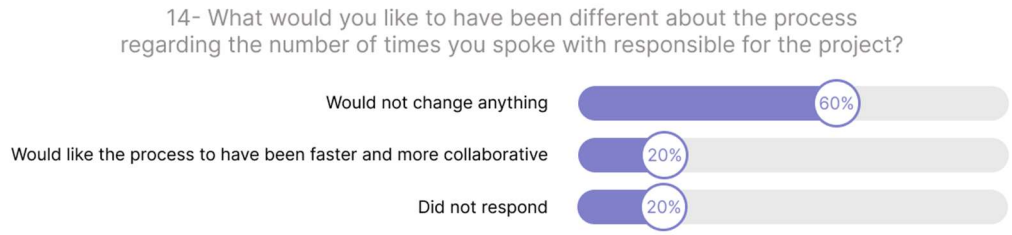


*Figure 66_Frequency of aspects mentioned by inhabitants in response to an **open-ended question** about the contact they had with the responsible for the project (e.g., the cooperative representative).*

The open-ended question **"What would you like to have been different in the process, regarding the elements you worked with: what would you like to have done that you didn't?"** was also posed (Figure 67), and 20% of respondents said they would not change anything. The remaining responses were given around two topics: (1) how to participate and (2) using digital technologies in the participation.

Although they referred to more than one way to participate, the cumulative answers show that inhabitants mostly would like to participate by drawing solutions. Making suggestions on a preliminary design or making choices between predefined options was also an often-mentioned way to participate. Handling objects was the third most preferred. A minor percentage of inhabitants said they would like to participate by talking and writing, and 5% added that they would like to be more involved in the decisions.

Regarding the use of digital technologies, using them in participation clearly stands out, opposing those who referred to using technologies in participation as irrelevant. Those who would like to use digital tools gave examples such as 3D digital models and material simulation systems. Also, games such as The SIMS (Electronic Arts Inc., 2000) were referred to. Twenty per cent of respondents did not answer this question.

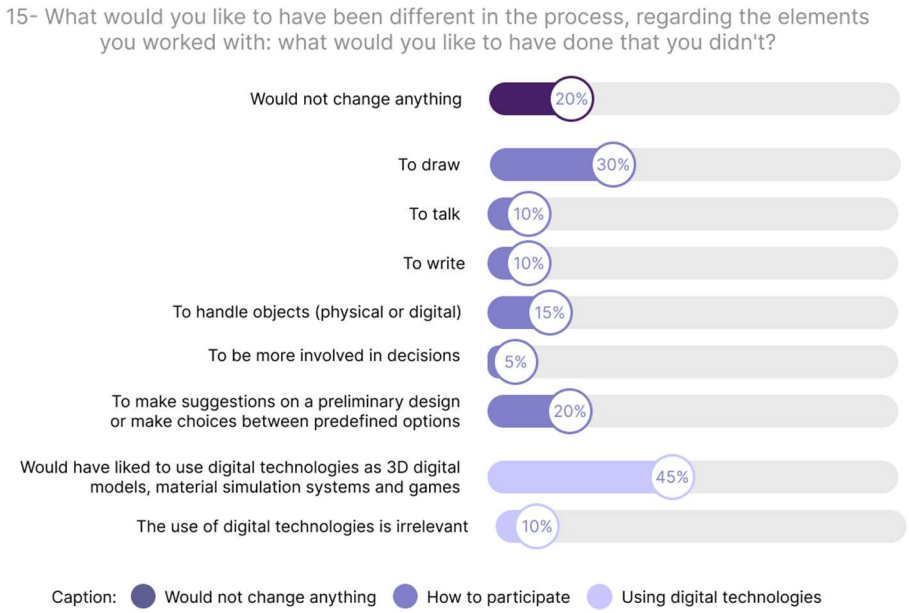


*Figure 67_Frequency of aspects mentioned by inhabitants in response to an **open-ended question** about ways in which they would have liked to participate.*

Finally, inhabitants were asked an open-ended question about whether **they could use a digital tool to define their house, whether they would like the architect to monitor the entire process, or if they would prefer to explore parts of the design alone** (or with family and friends) (Figure 68). Most inhabitants would like to explore the design alone, speaking occasionally with the designer when using a digital tool to define their houses. Only 20% responded that they would like to do it entirely with the designer.

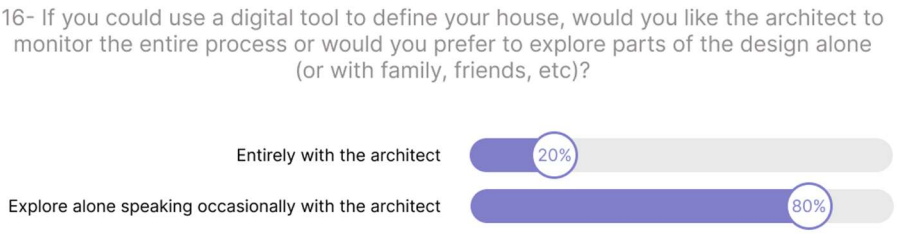


*Figure 68_Frequency of aspects mentioned by inhabitants in response to an **open-ended question** about how they would like to explore the design possibilities, using a digital tool, regarding the presence of the architect.*

3.5.2.3 Third phase: User requirements of a digital co-design tool

The third phase of the interviews with the inhabitants aimed to collect information about how a digital tool could have helped them in the participation process. This information would inform the user requirements of a digital tool that helps inhabitants to co-design their houses.

Different options were shown to the interviewees, representing four categories: **(1) the features (design phases in which inhabitants would like to make decisions), (2) types of interaction in the graphical user interface, (3) types of visualisation of the design and (4) devices.** The options were explained, and examples of existing systems or prototypes for housing customisation were shown to represent the possibilities. The inhabitants were then asked to make choices among the different options for each category. The four categories were shown to the interviewees randomly so that the results were not conditioned by the order in which the options were presented.

The options chosen to present to the interviewees derive from the review of computer systems for customising houses (see section 2.3.2). Some systems are available to be used (free or with a paid license), while others are academic research prototypes. The characteristics review of these systems raised the options presented to the inhabitants. This allowed to obtain data to define requirements for a housing co-design digital tool that meets the users' needs.

At this phase, the questions were **closed-ended**, and interviewees were asked to give two types of responses: 1) a binary response, in which inhabitants said whether they would like the tool to allow each of the options presented for each category, and 2) classification of options, in which inhabitants assigned an order of priority, where "1" refers to the option that has the most priority, and last place would be the option they find less relevant. These evaluations generate three ranks: **1) rank by importance (binary responses), 2) rank by classification (number of times the option was classified in the best position) and 3) rank by average (average of the score accumulated with the classification in each position).**

The binary responses define the rank by importance: the option in which the largest number of respondents answered "Yes" to the question "Would you like the tool to allow this option?" has a better position in this rank. Table 7 shows a hypothetical example of five individuals classifying three

options: three people said they would like the tool to have option 1, and two people would not. All of them (five people) would like to have option 2. Regarding option 3, one person would like to have this option, while the remaining four would not. Given this example, option 2 was the best classified in the rank by importance, as it obtained the largest number of people saying "Yes". The ordering of this rank is "1st: Option 2; 2nd: Option 1; 3rd: Option3", as the Table 8 shows.

Table 7_Example of ranking by importance: classified by five individuals.

	Yes	No
Option 1	3	2
Option 2	5	0
Option 3	1	4

Table 8_Example of the ranking by importance with order rearranged.

	Yes	No
Option 2	5	0
Option 1	3	2
Option 3	1	4

The rank by classification is defined by the number of times the option gets better positions, i.e., the options that have been classified most times as the first choice in the ordering by priorities have a better position in the rank. If there are ties, the position in the rank is defined by the following highest classification, namely, second place in the order of priorities, and so on.

Table 9 shows a hypothetical example of a rank by classification, with three options being classified by five individuals. Option 1 was classified as first priority by three people, in second place by one person and in third place by one person. Option 2 was classified as first place by one person, second place by two people, and third place by two people. Option 3 was classified in first place by three people, in second place by two people, and it was not classified in third place. In this example, options 1 and 3 are tied, as three people have classified them both as a first-place priority. The following highest classification (second place) was attributed to option 3 by two people and to option 1 by one person. Therefore, option 3 is best classified in rank by classification, as shown in Table 10.

Table 9_Example of priority classification by five people

	1st	2nd	3rd
Option 1	3	1	1
Option 2	1	2	2
Option 3	3	2	0

Table 10_Example of classification rank with order rearranged

	1st	2nd	3rd
Option 3	3	2	0
Option 1	3	1	1
Option 2	1	2	2

The rank by average is defined by the average score accumulated with the classification in each position. First place gives one score point, second place gives two score points, and so on. If an option is ranked in first place by two people, it accumulates 2 points (2 [people] x 1 [point]); if it is ranked in second place by three people, it accumulates 6 points (3 [people] x 2 [points]). The average is calculated over the sum of the accumulated score across all classifications an option gets. The lower the value, the better the position in the ranking (it means that better classifications were given more times) since better classifications accumulate lower scores.

In the example in Table 11, five people evaluated two options. Option 1 was evaluated by three people in first place and two in second place, accumulating a total of seven points (three points from

the first place and four points from the second place). The average score for this option is 3,5. Option 2 was evaluated once in first place (acquiring one point) and four times in second place (acquiring eight points), accumulating a total of nine points. The average score for this option is 4,5. Thus, having a lower average score, option 1 comes first in the rank by average, as it was better classified more times, obtaining lower values.

Table 11_Example of rank by average

	1st (1 pt)	2nd (2 pts)	Total score	Average
Option 1	3x	2x	(3x1) + (2x2) = 7	3,5
Option 2	1x	4x	(1x1) + (4x2) = 9	4,5

The following subsections, present the results of the third phase of the interviews with inhabitants regarding the classification in each category. These results are summarised in the three rankings. **The goal was to gather the requirements to define a digital tool to be used by people who join a housing cooperative.** As shown in Table 6, people generally join these institutions between 25 and 45 years old. Therefore, this age range was identified as the potential users of the digital tool intended to be defined. Although this phase of the interviews was carried out with all interviewees, only the responses of respondents within this age group were considered for defining user interface requirements.

3.5.2.3.1 Features requirements

Inhabitants were presented with seven options, about which they were asked to say whether they would like to have the opportunity to participate and, subsequently, organise them by priority. These options were: i) definition of the shape of the house; ii) automatic generation of the entire house's layout; iii) generation of the layout of each room step by step; iv) choice of the number and dimensions of each type of room; v) rearrange interior layout; vi) definition of limits and permeabilities; and vii) choice of finishing materials.

Defining the shape of the house means that they could decide the general characteristics of the house's volumetry, such as the shape (e.g. square, rectangular, "L" shaped, etc.), the height and the number of floors. These decisions would be made according to the context (e.g., whether they are houses or apartments) and the options previously defined by the designer. To exemplify this option, a screenshot (Figure 69) of the previous version of the Ikea Kitchen Planner system (Inter IKEA Systems B.V., 1999) was shown, in which users could choose the room's shape to start customising their kitchen with Ikea's products.

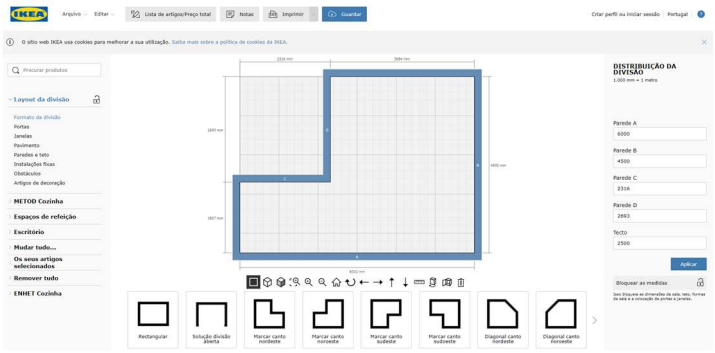


Figure 69_Screenshot of the Ikea Home and Kitchen Planner interface with options for choosing the room shape. Source: IKEA website (https://kitchenplanner.ikea.com/au/UI/Pages/VPUI.htm), currently not available.

The automatic generation of the entire house's layout implies that the user defines their space requirements. Then, the system would automatically generate possible solutions for the entire house layout in one step based on the user's input. As an example, an image (Figure 70) of the Layout Generation system (Veloso, Celani and Scheeren, 2018) was shown, representing the possible options generated by the system for customising the space of an apartment.

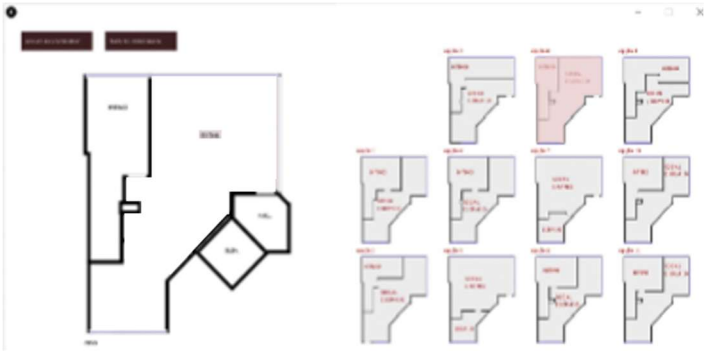


Figure 70_Graphical User Interface of the Layout Generation system with different system-generated options. Source: image adapted from Veloso, Celani and Scheeren (2018, p. 232)

The generation of the layout of each room step by step means that the inhabitant could define the interior of their house through the choice of pre-defined options for each room (e.g. choosing between several types of kitchen, several bathroom options, etc.) during the design definition. For this option, an image (Figure 71) of the I_Prefab Home system (Huang and Krawczyk, 2007) was shown, in which different layouts can be chosen for each room.



Figure 71_I_Prefab Home interface: selection from different options of kitchen layouts. Source: image adapted from Huang and Krawczyk (2007, p. 566).

Regarding **the number and dimensions of each type of room**, inhabitants could decide which rooms they would like their house to have, how many of each (e.g. two bedrooms, one living room, one kitchen, one bathroom, etc.) and define their dimensions. This could be done by choosing between pre-defined options (e.g. S, M, L) or even indicating the dimensions for each room (the area or measurements). To exemplify this option, an image (Figure 72) of the House Maker interface (MVRDV and Axis.fm, 2012) was shown, in which users can define these characteristics.

The interior layout refers to the positioning of the rooms (e.g. if the house is along a corridor, if the bathroom is between the two bedrooms or at the end of the corridor, or if the kitchen is next to the living room, etc.). To exemplify this option, an image of the House Maker interface (MVRDV and Axis.fm, 2012) was shown, where users can define the location of rooms while seeing the results in real time (Figure 73).

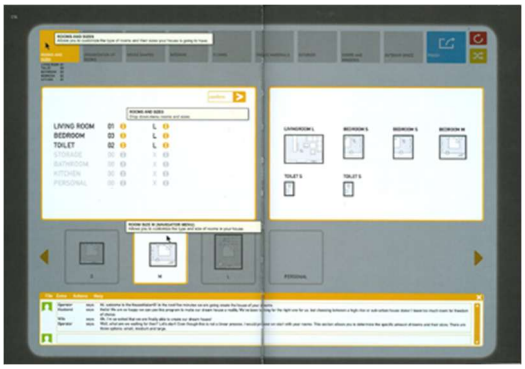


Figure 72_House Maker interface for defining "Rooms and sizes". Source: MVRDV and Axis.fm (2012, p. 176)



Figure 73_House Maker interface for defining Organisation of rooms. Source: MVRDV and Axis.fm (2012, p. 178)

Limits and permeabilities refer to the relationship between spaces, that is, the definition of where the openings and connections between rooms are (e.g. if the kitchen and living room are an open space). In this option, an image (Figure 74) of the RoomSketcher system (RoomSketcherAS, 2007) was shown, where only the walls and openings are represented on a floor plan.

Finishing materials are options for users to customise their houses in terms of finishings (e.g. stone for kitchen countertops, flooring, wall covering, etc.). To exemplify this option, an image (Figure 75) of the RoomSketcher system (RoomSketcherAS, 2007) was shown, in which users can drag materials from a library to the design.

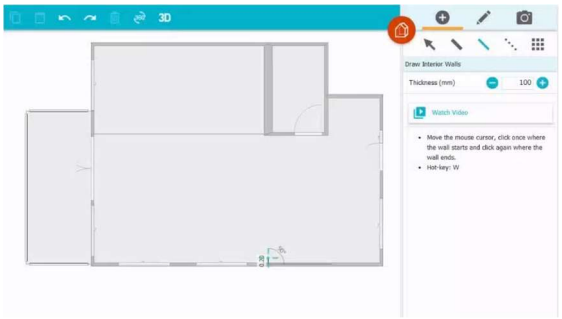


Figure 74_RoomSketcher interface: creating walls and openings. Source: RoomSketcher website (https://www.roomsketcher.com/)

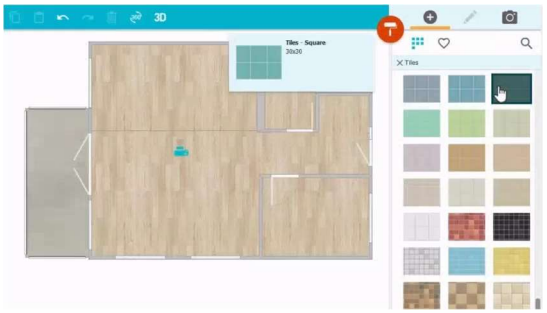


Figure 75_RoomSketcher interface: material assignment. Source: RoomSketcher website (https://www.roomsketcher.com/)

The results of the inhabitants' responses in this category are summarised in Table 12. Although the responses of 10 respondents were considered (as they were within the age range of potential users of the tool: between 25 and 45 years old), two of them did not order the options by priority, so they were excluded from the count for the ranks by classification and by average. The ten respondents answered the question about the rank by importance.

Table 12 shows the results of the classification for the Features category. In the left column, there are the seven elements that were classified: (1) House shape, (2) Automatic generation, (3) Layout step by step, (4) Number and dimensions of rooms, (5) Interior layout, (6) Limits and permeabilities, and (7) Finishing materials. The column “Classification” is the order by priority, with classifications from 1st to 7th place. “CL” indicates the number of people who assigned the classification, and “PTS” indicates the corresponding score. The column “Average” is the average of the accumulated score from all points gathered in each priority position. The right column is the classification of the binary responses to the question “Would you like the tool to allow this option?” with “Yes” or “No” as options to answer.

Table 12_Results of the inhabitants' classification for the Features category.

		Classification							Average	"Would you like the tool to allow this option?"	
		1st	2nd	3rd	4th	5th	6th	7th		Yes	No
House shape	CL	2	2	0	0	1	2	1	-	9	1
	PTS	2	4	0	0	5	12	7	4,29		
Automatic generation	CL	1	0	1	0	1	0	5	-	5	5
	PTS	1	0	3	0	5	0	35	6,29		
Layout step-by-step	CL	2	1	1	2	0	2	0	-	9	1
	PTS	2	2	3	8	0	12	0	3,86		
Number and dimensions of rooms	CL	2	4	2	0	0	0	0	-	10	0
	PTS	2	8	6	0	0	0	0	2,29		
Interior layout	CL	0	1	1	3	2	1	0	-	10	0
	PTS	0	2	3	12	10	6	0	4,71		
Limits and permeabilities	CL	0	0	0	3	2	1	2	-	7	3
	PTS	0	0	0	12	10	6	14	6,00		
Finishing materials	CL	1	0	3	0	2	2	0	-	10	0
	PTS	1	0	9	0	10	12	0	4,57		
		Total responses: 8								Total responses: 10	

As shown in Table 12, the "House shape", "Layout step by step", and the "Number and dimensions of rooms" were all classified two times in the first **level of priority**. As these options are tied, the second level is what determines the priority: "House shape" was classified as the second level of priority two times; "Layout step-by-step" once; and "Number and dimensions of rooms" four times. This means that the latter gets the first place in the ranking by classification (Table 13). The "House shape" stays in the second, and the "Layout step by step" in the third. The fourth place in the rank goes to the "Finishing materials" as, although it is tied with the "Automatic generation" in the first and second level of priorities (one and zero, respectively), it was classified more times in the third level of priority (three times) than the "Automatic generation" (once), which gets the fifth place in the ranking. Regarding the remaining two options, the "Interior layout" gets the sixth place in the ranking, as it was classified more times (once) in the second level of priority than the "Limits and permeabilities", which gets the last place in the ranking (both had zero votes as the first level of priority).

Regarding the **rank by average** (Table 14), the best scenario was to get 1,14 of average, which would mean that the option was classified as the first level of priority by the eight respondents, gathering 8 points. The option "Number and dimensions of rooms" acquires the first place, as it was classified more times in better priority positions, gathering the lowest points (2,29 on average). The second place in the rank by average goes to the option "Layout step-by-step", which accumulated 3,86 on average. The following position in the rank goes to the "House shape" with an average of 4,29. The "Finishing materials" occupies the fourth place in this rank, with an average of 4,57. The "Interior layout" occupies the fifth place with 4,71 on average. The option "Limits and permeabilities" gathered a score with an average of 6,00, as its best classification was the fourth level of priority, occupying the sixth position in the rank. Finally, the "Automatic generation" occupies the last place in this rank, with

an average of 6,29. Although this option was classified once in the first level of priority, more than half of the respondents classified it in the lower level of priority, giving many points to this option.

The **rank by importance** (Table 15) was defined by the binary responses to the question "Would you like the tool to allow this option?" given by ten interviewees. The "Number and dimension of rooms", "Interior layout", and "Finishing materials" are both in the first place, as they had all the respondents (ten) saying "Yes". The "Layout step-by-step" and "House shape" are both in fourth place, with nine respondents saying "Yes" and one saying "No". The "Limits and permeabilities" gets the sixth place in the rank with seven "Yes", and the last place goes to the "Automatic generation" with half of the respondents saying "Yes" and the other half saying "No".

Table 13_Rank by classification for the Features category

Rank by classification	
1st	Number and dimensions of rooms
2nd	House shape
3rd	Layout step-by-step
4th	Finishing materials
5th	Automatic generation
6th	Interior layout
7th	Limits and permeabilities

Table 14_Rank by average for the Features category

Rank by average	
1st	Number and dimensions of rooms
2nd	Layout step-by-step
3rd	House shape
4th	Finishing materials
5th	Interior layout
6th	Limits and permeabilities
7th	Automatic generation

Table 15_Rank by importance for the Features category

Rank by importance	
1st	Number and dimensions of rooms
1st	Finishing materials
1st	Interior layout
4th	Layout step-by-step
4th	House shape
6th	Limits and permeabilities
7th	Automatic generation

3.5.2.3.2 Type of graphical interaction

The type of graphical interaction defines how users interact with the user interface, that is, the actions they must perform to make choices within the design process. In this category, six options were presented: i) drag-and-drop/ click-and-place; ii) click on images or buttons; iii) draw; iv) choose from a catalogue; v) sliders; and vi) fill-in fields.

The **drag-and-drop/click-and-place** option means that the user can drag elements or click on the option they want (to select it) and click again where they want to place it. This can be done by choosing from predefined options in a library and placing them into the design or moving objects within the design. As an example, a screen recording of the Roomsketcher system (RoomSketcherAS, 2007) was shown with the system's material allocation interface (Figure 75), in which it is possible to see the action of dragging a material to the floorplan.

Clicking on images or buttons assumes that there are also pre-defined options, which users choose by clicking on them. These options can be images or buttons in menus, which, when activated, appear automatically in the design without the need to place them. To illustrate this option, a few seconds of a video from the MyChanges platform (Eloy *et al.*, 2021a) was shown (Figure 76), which shows the interaction of clicking on buttons and the result appearing automatically in the design.



Figure 76_MyChanges interface: options selection through buttons: a button is clicked on the side menu, and the result is reflected in the main screen. Source: Eloy et al. (2021a) (https://ieeevr.org/2021/program/videos/#V1001)

The "**Draw**" type of interaction means there are no pre-defined options, and the user creates the designs from scratch, positioning the walls according to their preferences. As an example, a screen recording from the Sweet Home 3D system (ETeks, 2006) was shown, which shows the action of drawing walls (Figure 77).

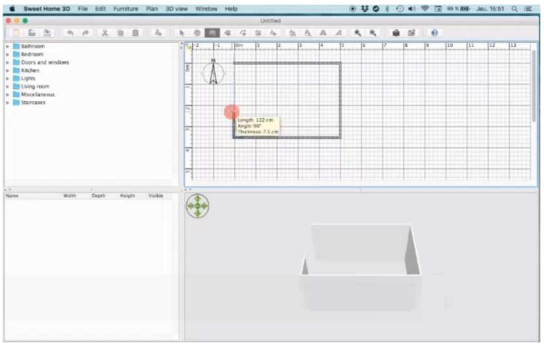


Figure 77_Sweet Home 3D interface: walls being drawn. Source: Sweet Home 3D website (https://www.sweethome3d.com/pt/).

Choosing from a catalogue means the user is presented with the options one by one, as if they were leafing through a catalogue. To go through the options, the user clicks, e.g., on "next" and "previous" buttons. To exemplify this type of interaction, an animation was shown with images from the Shaper-GA system interface (Kwiecinski *et al.*, 2016), simulating the user moving to the following options by clicking on the forward arrow (Figure 78).



Figure 78_Shaper_GA interface. Source: Kwiecinski et al., (2016, p. 357).

Sliders are sliding bars associated with specific design characteristics. By interacting with these bars (dragging to the right or left), the user influences the design, which is automatically updated according to user interaction. They can be used to define, e.g., the dimensions of spaces. A part of a video from the Architechtures software SmartScapes Studio SL (2019) was shown to exemplify how the interaction with these bars influences the dimensions of the spaces in the floorplan (Figure 79).



Figure 79_Architechtures interface: interaction with sliders of different settings is made in the left menu, and the results are shown in the floorplan. Source: Architechtures website (https://architechtures.com/?lang=en_US)

In the **field-filling option**, users can fill in fields as in a questionnaire. This interaction depends on the design phase in which it is applied. Still, it can serve, e.g., to define the initial requirements in an automatic generative process or to define the length of each wall, whose configuration is updated in the project as the values are introduced. It can be done by inserting values in the fields or choosing predefined options from a drop-down list. As an example, a screen recording of the previous version of the Ikea Kitchen Planner system (Inter IKEA Systems B.V., 1999) was shown, which demonstrates the filling of fields that adjust the dimensions of the walls in real-time (Figure 80).

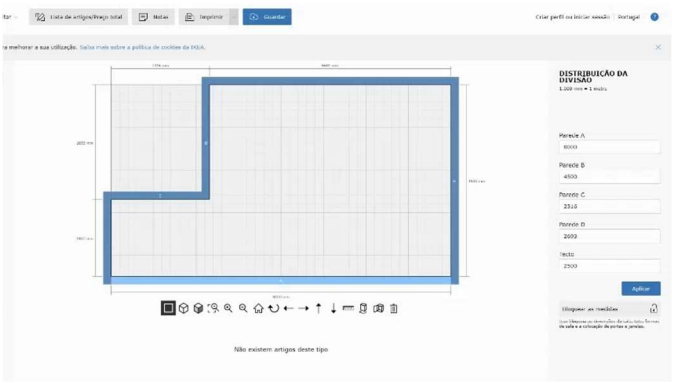


Figure 80_Ikea Kitchen Planner interface: the possibility of adjusting the size of the walls by filling in the fields in the side menu. Source: IKEA website (https://kitchenplanner.ikea.com/au/UI/Pages/VPUI.htm), currently not available.

Table 16 shows the results of the classification for the Graphical Interaction category. Eight interviewees classified the six options: (1) Drag and drop / Click and place; (2) Click on images or buttons; (3) Draw; (4) Choose from a catalogue; (5) Sliders; and (6) Fill-in fields. The ten interviewees answered with “Yes” or “No” to the question of whether they would like a co-design digital tool to have each of the six interaction options.

Table 16_Results of the inhabitants' classification for the Graphical Interaction category.

		Classification						Average	"Would you like the tool to allow this option?"	
		1st	2nd	3rd	4th	5th	6th		Yes	No
Drag and drop / Click and place	CL	3	2	3	0	0	0	-	9	1
	PTS	3	4	9	0	0	0	2,67		
Click on images or buttons	CL	2	3	0	1	1	1	-	10	0
	PTS	2	6	0	4	5	6	3,83		
Draw	CL	0	1	0	2	1	4	-	6	4
	PTS	0	2	0	8	5	24	6,50		
Choose from a catalogue	CL	1	1	0	2	1	3	-	5	5
	PTS	1	2	0	8	5	18	5,67		
Sliders	CL	2	1	2	2	1	0	-	8	2
	PTS	2	2	6	8	5	0	3,83		
Fill-in fields	CL	0	0	3	1	4	0	-	7	3
	PTS	0	0	9	4	20	0	5,50		
		Total responses: 8							Total responses: 10	

The type of interaction "Drag and drop/ Click and place" was classified by three people in the first **priority level**. This option was the best classified among all the other options and, therefore, gets the first place in the ranking by classification (Table 17). The options "Click on images or buttons" and "Sliders" were both classified twice as first priority level. From both, the option "Click on images or buttons" got the second place in the rank, as it had three votes as a second priority, while the "Sliders" had only one, getting third place. "Choose from a catalogue" is in the fourth position, with one person scoring it as the first priority level. From the remaining options, both without votes in the first level of priority, the "draw" option gets the fifth place as it was classified once as the second priority level, leaving the "fill-in fields" in the last position on the rank with zero votes on the second priority level.

The "Drag and drop" option leads the **rank by average** (Table 18), having accumulated the lowest score: an average of 2,67 points (the best scenario would be that all eight interviewees who assigned ratings had classified it in the first priority level, thereby accumulating 8 points and an average of 1.33). The second place is occupied by both the "Click on images or buttons" and "Slider" options, with an average of 3,83 points each. The "fill-in fields" option occupies the fourth place with 5,50 points on average. The option "Choose from a catalogue" gets the fifth place in the ranking with 5,67. Finally, the "draw" option comes in sixth place in the rank by average, as it accumulated 6,50 points on average.

Regarding the **rank by importance** (Table 19), the first place goes to "Click on images and buttons", as all the respondents said they would like to have this option on the interface. The "Drag and drop" got the second place in the ranking, with nine people saying "Yes". The option "Sliders" comes next, in third place with eight votes for "Yes". Seven people would like to have the "Fill-in fields" in the tool, giving this option the fourth place. With six votes for "Yes", the "Draw" option occupies the fifth place,

followed by the “Choose from a catalogue” that occupies the sixth and last place in the rank, with a tie of five respondents saying “Yes” and five saying “No” to this option.

Table 17_Rank by classification for the Graphical Interaction category

Rank by classification	
1st	Drag and drop
2nd	Click on images or buttons
3rd	Sliders
4th	Choose from a catalogue
5th	Draw
6th	Fill-in fields

Table 18_Rank by average for the Graphical Interaction category

Rank by average	
1st	Drag and drop
2nd	Click on images or buttons
2nd	Sliders
4th	Fill-in fields
5th	Choose from a catalogue
6th	Draw

Table 19_Rank by importance for the Graphical Interaction category

Rank by importance	
1st	Click on images or buttons
2nd	Drag and drop
3rd	Sliders
4th	Fill-in fields
5th	Draw
6th	Choose from a catalogue

3.5.2.3.3 Type of visualisation

The type of visualisation defines how the housing design is presented. Six options were shown: i) schematic drawings, ii) schematic three-dimensional (3D) model, iii) detailed drawings, iv) humanised floorplans, v) interior views, and vi) interactive/walkthrough 3D model.

The drawings refer to floorplans, sections and elevations. **Schematic drawings** are presented as matrices or spatial diagrams, and different colours can represent different spaces. The example shown to the interviewees was an image of the Shaper-GA interface (Kwiecinski *et al.*, 2016), in which the project is represented in a schematic floorplan (Figure 81).

The **schematic 3D model** follows the same logic as schematic drawings, however, it is defined with volumes in cubic matrices. The example shown to the inhabitants was a screenshot from a video showing the Group Forming system (Ong, Janssen and Lo, 2013), which uses this type of representation (Figure 82).

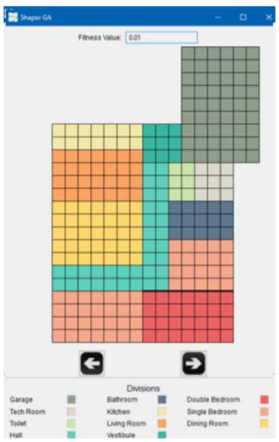


Figure 81_Shaper-GA: : representation of the design in a schematic floorplan. Source: Kwiecinski et al., (2016, p. 357).

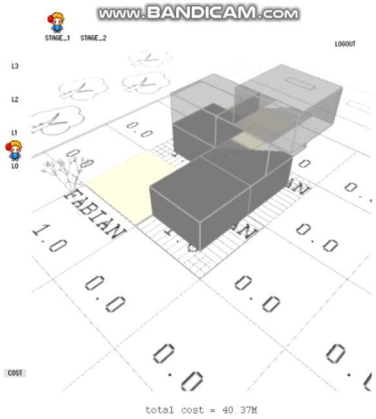


Figure 82_Group Forming: representation of the design in a schematic 3D. Source: https://vimeo.com/26638743

Detailed drawings refer to drawings with details according to scale, such as wall thicknesses, elevation heights and planimetric dimensions, an indication of the opening direction of doors and windows, designation of rooms, indication of areas, representation of fixed furniture, etc.

Humanised floorplans are simplified (commonly known as clean floorplans), representing finishings and furniture arrangement. Representations of people "inhabiting" the space can also be placed to represent the human scale.

The examples shown were images from the RoomSketcher system (RoomSketcherAS, 2007), in which the design appears represented in a detailed floorplan (Figure 83) and a humanised floorplan (Figure 84).



Figure 83_Roomsketcher interface: detailed floorplan representation. Source: RoomSketcher website (https://www.roomsketcher.com/).

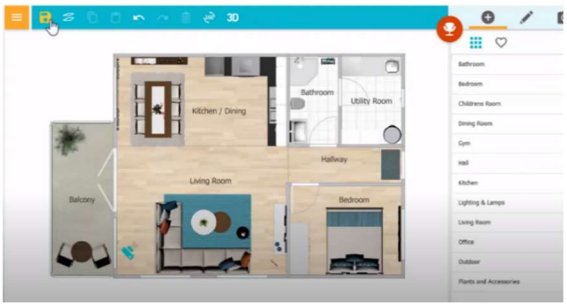


Figure 84_Roomsketcher interface: humanised floorplan representation. Source: RoomSketcher website (https://www.roomsketcher.com/).

Interior views are static representations (images) of the interior of houses from an immersive point of view, that is, as if the user were inside the house. As they are representations of a design, they are not photographs but simulations (renders).

As the name suggests, the **interactive/walkthrough 3D digital model** allows the user to interact with it and see it from different viewpoints, such as an aerial view (bird-eye) or immersive views. Users can also "walk" through the space (walkthrough).

The RoomSketcher (RoomSketcherAS, 2007) was shown again to exemplify these types of visualisation, where the user can see a view of the interior design at the human scale (Figure 85), and a short video was also shown to exemplify the visualisation of an interactive 3D model (Figure 86).



Figure 85_Roomsketcher: static interior view. Source: RoomSketcher website (https://www.roomsketcher.com/).



Figure 86_Roomsketcher: aerial view of a 3D digital model. Source: RoomSketcher website (https://www.roomsketcher.com/).

The results for the Type of visualisation category are shown in Table 20. For this category, nine people organised the options by priority level, and the question of binary response was answered by

the ten interviewees within the age range identified as potential users. Six options were classified: (1) Schematic drawings; (2) Schematic 3D model; (3) Detailed drawings; (4) Humanised floorplans; (5) Interior views; and (6) Interactive 3D model.

Table 20_Results of the inhabitants' classification for the Type of visualisation category.

		Classification						Average	"Would you like the tool to allow this option?"	
		1st	2nd	3rd	4th	5th	6th		Yes	No
Schematic drawings	CL	0	0	0	0	5	4	-	2	8
	PTS	0	0	0	0	25	24	8,17		
Schematic 3D model	CL	0	0	0	1	4	4	-	5	5
	PTS	0	0	0	4	20	24	8,00		
Detailed drawings	CL	1	1	1	5	0	1	-	9	1
	PTS	1	2	3	20	0	6	5,33		
Humanised floorplans	CL	1	2	5	1	0	0	-	9	1
	PTS	1	4	15	4	0	0	4,00		
Interior views	CL	0	5	2	2	0	0	-	9	1
	PTS	0	10	6	8	0	0	4,00		
Interactive 3D model	CL	7	1	1	0	0	0	-	10	0
	PTS	7	2	3	0	0	0	2,00		
		Total responses: 9							Total responses: 10	

The "Interactive 3D model" was classified as the first **level of priority** by most of the respondents (7), giving this option the first place in the rank by classification (Table 21). Although both "Detailed drawings" and the "Humanised floorplans" had one person classifying them as first priority, the "Humanised floorplans" got the second place in the ranking because it was classified twice as second level of priority. Therefore, "Detailed drawings" occupies the third place in the rank with one vote on the second priority level. The three remaining options were not classified as first priority level. The option"Interior views" was classified by five people in the second priority level, earning fourth place. The fifth place goes to the option "Schematic 3D model", with its best classification being the fourth level of priority, and in last place is the "Schematic drawings", which was classified as the fifth level of priority by five people.

In the **rank by average** (Table 22), the "Interactive 3D model" is again in first place, with an average of 2 points: the closest to the best scenario (if the nine respondents classified it as first priority, it would have an average of 1,5). Tied in second place are the options "Humanised floorplans" and "Interior views", with averages of 4 points. The "Detailed drawings" option is in the fourth position in the rank, with 5,33 on average. The "Schematic 3D model" is in fifth place as it accumulated 8 points on average, and finally the "Schematic drawings" is in the last position with an average of 8,17.

The first place in the **rank by importance** (Table 23) goes to the "Interactive 3D model", as the ten respondents would like the tool to have this type of visualisation. The "Humanised floorplans", "Detailed drawings", and "Interior views" are all in second place with nine votes on "Yes". The

"Schematic 3D model" is in fifth place with five people saying "Yes". Most respondents (eight) would not like to have the "Schematic drawings" as a type of visualisation in the proposed interface. Therefore, this option stayed in last place in the ranking.

Table 21_Rank by classification for the Type of visualisation category

Rank by classification	
1st	Interactive 3D model
2nd	Humanised floorplans
3rd	Detailed drawings
4th	Interior views
5th	Schematic 3D model
6th	Schematic drawings

Table 22_Rank by average for the Type of visualisation category

Rank by average	
1st	Interactive 3D model
2nd	Humanised floorplans
2nd	Interior views
4th	Detailed drawings
5th	Schematic 3D model
6th	Schematic drawings

Table 23_Rank by importance for the Type of visualisation category

Rank by importance	
1st	Interactive 3D model
2nd	Humanised floorplans
2nd	Detailed drawings
2nd	Interior views
5th	Schematic 3D model
6th	Schematic drawings

3.5.2.3.4 Devices and interface

Examples of five devices where the tool could be used were shown. These devices are i) computer, ii) smartphone, iii) tablet, iv) interactive digital table, and v) Head-Mounted Display (HMD).

Computers include desktops and laptops. Interaction with these devices is done using peripherals, such as a mouse, keyboard and monitors. To exemplify this option, an image was shown representing the interaction with a computer (Figure 87).



Figure 87_A person using a computer. Source: Image by Iftikhar Alam on Vecteezy (https://www.vecteezy.com/photo/33880753-top-view-of-businessman-working-on-computer-at-desk-in-office-business-concept-high-angle-view-of-male-hands-typing-on-computer-keyboard-while-working-in-office-ai-generated).

The smartphone is a mobile device with touchscreen interaction, which is generally present in people's daily lives. The tablet, also mobile and with touchscreen interaction, is a device that has a larger screen size compared to the smartphone. Images were shown from the MyChanges project (Eloy *et al.*, 2021a), which represent the visualisation and interaction on mobile and touchscreen devices such as smartphones (Figure 88) and tablets (Figure 89).

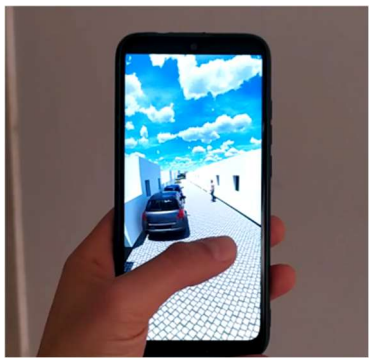


Figure 88_MyChanges being used to visualise 360º images on a smartphone. Source: Eloy et al. (2021a) (https://ieeevr.org/2021/program/videos/#V1001)



Figure 89_MyChanges being used to customise facades on a tablet. Source: Eloy et al. (2021a) (https://ieeevr.org/2021/program/videos/#V1001)

The interactive digital table is another touchscreen device with a significantly larger screen area than the previous one. It allows several people to interact simultaneously if it is a multi-touch screen. This device requires the users to be physically in the same space. As an example, an image of a system designed for the co-design of buildings (Mcleish, 2003) was shown, whose interaction is done using a digital table (Figure 90).

Head-Mounted Displays (HMD) allow immersive visualisation, and the interaction is done with controllers. These devices can be used for virtual reality (VR) and augmented reality (AR). An image (Figure 91) representing a virtual reality HMD device was shown to represent this device option.



Figure 90_A platform for Consumer-driven participative design of open (source) buildings: two people using a digital table to customise a housing design. Source: Mcleish (2003, p. 65).



Figure 91_A person using a virtual reality HMD. Author's source.

Table 24 shows the results for the Devices category. Eight respondents organised five options by priority: (1) Computer; (2) Smartphone; (3) Tablet; (4) Interactive digital table; and (5) Head-mounted display (HMD). The ten respondents answered the question about the rank by importance.

Table 24_Results of the inhabitants' classification for the Devices category.

		Classification					Average	"Would you like the tool to allow this option?"	
		1st	2nd	3rd	4th	5th		Yes	No
Computer	CL	2	2	3	1	0	-	10	0
	PTS	2	4	9	4	0	3,80		
Smartphone	CL	2	1	2	0	3	-	8	2
	PTS	2	2	6	0	15	5,00		
Tablet	CL	0	2	2	4	0	-	8	2
	PTS	0	4	6	16	0	5,20		
Interactive digital table	CL	0	3	1	3	1	-	5	5
	PTS	0	6	3	12	5	5,20		
Head- Mounted Display (HMD)	CL	4	0	0	0	4	-	6	4
	PTS	4	0	0	0	20	4,80		
		Total responses: 8						Total responses: 10	

The "HMD" was the device with most people classifying it in first **level by priority** (four), acquiring the first place in the rank by classification (Table 25). The "Computer" and "Smartphone" were both classified twice in the first priority level. The "Computer" was classified in the second level twice, earning the second place, and the "Smartphone" was classified once in the second level of priority, giving it the third place in the rank. The "Interactive digital table" goes in fourth place, with better classification in the second priority level than the "Tablet", which goes in fifth and last place.

The **rank by average** (Table 26) has the "Computer" in first place, with the average (3,80 points) closest to the best scenario. The best scenario would be the eight respondents classifying it as first place priority, giving an average of 1,6. Following the "Computer" in the rank, there is the "HMD" with 4,80 of average. The third place goes to the "Smartphone", which acquired an average of 5 points. The "Tablet" and "Interactive digital table" are tied with 5,20 points on average at the bottom of the rank.

Finally, the **rank by importance** (Table 27) has the option "Computer" in the first place, as all ten respondents would like to use the tool on this device. The "Tablet" and "Smartphone" come in second place with eight "Yes" responses. The "HMD" stayed in fourth place as it gathered six people saying "Yes". The last place in this rank goes to the "Interactive digital table", as half of the respondents (five) would like to use the tool on this device, and the other half (five) would not.

Table 25_Rank by classification for the Devices category

Rank by classification	
1st	Head- Mounted Display (HMD)
2nd	Computer
3rd	Smartphone
4th	Interactive digital table
5th	Tablet

Table 26_Rank by average for the Devices category

Rank by average	
1st	Computer
2nd	Head- Mounted Display (HMD)
3rd	Smartphone
4th	Tablet
4th	Interactive digital table

Table 27_Rank by importance for the Devices category

Rank by importance	
1st	Computer
2nd	Tablet
2nd	Smartphone
4th	Head- Mounted Display (HMD)
5th	Interactive digital table

3.5.3 Discussion

According to the data collected, **inhabitants who join housing cooperatives are between 25 and 45 years old**. Even though older people were interviewed, they have already been residents of cooperatives for many years. Older inhabitants live in older cooperatives, where they signed up when they were still young or at a time when there was a great demand for better living conditions but little economic power. It was also noticed that younger people generally have a **good relationship with technology and currently have a higher level of education t**han young people had in the past. Although the cooperatives mentioned having held processes with homogeneous groups of people, the characteristics of these groups have changed over the years. The oldest cooperatives had groups with a low level of education and no relationship with technology, while in the most recent cooperatives, the groups were people with more education and much more involved with technology (see Table 6, in section 3.5.1).

The **potential users** of the proposed interface will not be those who were interviewed, but rather people who, in the future, join a housing cooperative. Still, it was important to carry out the interviews to understand their characteristics and foresee the characteristics of future inhabitants of housing cooperatives. Therefore, considering the digital and social transformation that has been occurring over time, confirmed by the characteristics of the cooperatives' members, it was considered that the potential users are young people, between 25 and 45 years of age, from the middle or lower middle class, without difficulties in using a digital tools, since they will potentially be more educated both in terms of education and digital literacy.

As mentioned before, the cooperatives work with the middle classes and, as such, the inhabitants look for these institutions for affordability. As seen, most of them do not look for a participatory process as they do not know they would have this opportunity. Despite this, when asked, **inhabitants reported that they enjoyed having contact with the design** (even though it was just to see it) and showed an interest in participating more actively and exploring the design possibilities. However, the inhabitants' responses are in line with what was said by the cooperatives regarding the process, i.e., about the phases in which they participate. The results confirm that inhabitants are involved in phases that do not significantly influence the layout of the houses, such as the choice of finishes. Their involvement in defining the initial requirements does not mean that they actively participate in defining the design, as the design is made by the architect. According to Van Der Linden, Dong and Heylighen (2018), such a situation leads to designs based on the architect's subjective interpretations of the participants' requirements that may not reflect the users' preferences.

Cooperatives' representatives justified the lack of participation, e.g., in the definition of common spaces, with the lack of interest from the inhabitants. However, data analysis shows that **inhabitants have an interest in participating**, although they do not always use this possibility when they have the

opportunity. It might be a matter of misinformation since, according to Contreras-Espinosa et al. (2023) citizens are not aware of their relevance in the development of their living spaces. Some professionals interviewed share the same opinion. According to them, inhabitants have an interest in participating, especially when the designs directly affect their lives, however, sometimes people do not participate for cultural issues, e.g., because they do not know they are allowed to, or they think their voice is not important. Accordingly, inhabitants' answers to the question about their perspective on whether their participation makes a difference (especially those who responded that it does not because they do not have architectural knowledge) confirm that they do not have the perception of their importance in the design process. In addition, inhabitants who participated say, based on what they experienced, that they feel that participation is ineffective, as the voting system reduces their input to one among many, without meaningful individual collaboration that could make their voice truly count.

Regarding the **inhabitants' satisfaction with the process**, opposing to what housing cooperatives said (that the inhabitants had no interest in collaborating on the design definition since they did not comment on it), inhabitants mentioned that **they would like to have participated more, to have had more contact with the architect and they would also like the process to have been more collaborative**. People who did not participate have the desire to do it and believe that the result would be better suited to their needs. Besides, although the majority of those interviewed said they were satisfied with the result, inhabitants also said that they would make changes, which shows that they were not completely satisfied. Some of the changes mentioned were related to aspects they did not define, such as the rooms' size and the layout configuration. This data suggests that more collaborative approaches need to be held, e.g., involving the inhabitants individually in the design definition of their houses. The literature shows that allowing inhabitants to collaborate in the design definition creates a feeling of belonging and satisfaction (Sanoff, 2000; Ammar, Hj Ali and Yusof, 2013).

Another relevant aspect concerns the **elements shown to inhabitants to represent the design and their understanding of it**. According to both inhabitants and cooperatives' representatives, floorplans are mostly shown. However, technical drawings are difficult to read by non-specialists in architecture, as they may not have the same spatial perception as the architects. Inhabitants reported no difficulties in understanding technical drawings if these are complemented with other less abstract ways of displaying the project, such as perspectives of spaces. In some cases, 3D images were shown, and this was mostly the reason why they did not have difficulties in understanding the design. Most inhabitants said that there were no differences between what they saw in the project and the final built result, which confirms that they had understood the design. Therefore, digital technologies play a crucial role in this topic, as they allow the production of 3D digital models that can easily provide different perspectives. Accordingly, the literature shows that 3D interactive and immersive visualisation allows non-specialists to better understand the space (Al-Kodmany, 2001; Salter *et al.*,

2009; Faliu *et al.*, 2018). A small percentage of the inhabitants interviewed said they would have understood the design even if the 3D images were not shown. A potential explanation is that these inhabitants are familiar with technical drawings because they have previously had contact with these elements in their profession or because they deal with people who work with it (see Table 6).

According to both professionals and cooperatives representatives, sometimes people don't know what they want, or they "just want a house". However, **they can form more informed opinions when a base project is shown**, and seeing tangible proposals sparks their interest, according to the data collected from the interviews with inhabitants. In addition, having contact with the design in the early phases, as the design definition, helps non-designers understand the possibilities and constraints, fostering them to think about their requirements and priorities. Inhabitants said they would like to make decisions about the spaces of their houses and be involved in their housing design by having a starting solution to work on and improve on it with predefined options to choose from. As mentioned, this allows them to form opinions and collaborate by improving the design instead of having to start from scratch. **Providing predefined options** is a way of giving end users the freedom to choose and simultaneously presenting design possibilities they might not know. Also, predefined options can be combined to create customised solutions. As stated by Brandt, Binder and Sanders (2013), a toolkit with a limited group of components has the potential to create a wide variety of solutions when such components are combined. These components can be visual elements of, e.g., different room layouts, which inhabitants can choose to customise their houses without the need for having technical knowledge, as it is guaranteed in the options presented to them. According to Kwiecinski, Markusiewicz and Pasternak (2017), the effectiveness of a participatory design process lies in embedding the technical knowledge in the possibilities provided, which are defined by the architects.

The **Inhabitants also said they would like to use digital technologies** to handle 3D objects and simulate applying finishing materials. Indeed, digital technologies can support participation by facilitating informed decision-making. Digital technologies, such as 3D simulation systems, are playful and can easily provide different perspectives. Such perspectives improve understanding of space from non-specialists in architecture, allowing them to make informed decisions (Faliu *et al.*, 2018). This was confirmed during the interviews, when the inhabitants reported having no difficulties in understanding the floorplans when complemented with perspectives taken from 3D models. Also, technologies such as generative design can provide viable base solutions aligned with the user's requirements, as it allows the automatic generation of diverse possibilities that respond to the diversity of end-users needs (Kwieciński and Słyk, 2023; Tomić, Krasic and Kocić, 2023).

In the third phase of the study, interviews with inhabitants were conducted to identify more specific design elements, i.e., requirements for a graphical user interface that could facilitate their active involvement in the design process. When asked about the stages of the housing definition

process in which they wished to contribute, the prioritisation of options revealed a **clear preference among most participants for engaging across multiple phases**. Notably, while the categories of "Limits and permeabilities" and "Automatic generation" received comparatively fewer votes, they were still voted by at least 50% of the respondents. These findings suggest that a hybrid approach may be more appropriate. The various design tasks can coexist, enabling a combination of automated generation with manual customisation. For instance, the system could produce an initial design automatically based on user-defined parameters, which inhabitants could then adjust through complementary steps. This layered and participatory method is exemplified by solutions such as the ABC-based Customised Mass-Housing Generator (Benrós and Duarte, 2009).

Regarding the **types of interaction, the "Drag and drop" and "Click on images or buttons"** options are in first or second place in all three ranks. More than one type of interaction can be used in the interface, depending on the task and the design phase, although the better classified ones must be prioritised.

Concerning the **type of visualisation, the option "Interactive 3D model"** is in first place, and "Humanised floorplans" is in second place in all three ranks. Also, both "Detailed drawings" and "Interior views" are in the top 3 at least in two ranks. Using more than one type of visualisation can be beneficial if they complement each other, as gathered from the results of the first phase of the interviews with inhabitants. Humanised floorplans and interior views are static representations of different viewpoints that can be visualised in an interactive 3D model. These types of visualisation are similar, as they are easy to understand by non-experts in architecture because they are the closest simulation of reality. On the other hand, detailed drawings provide more detailed information, such as, e.g., dimensions.

Regarding **the devices, the computer was the only device that always remained in the top two places in all ranks.** The HMD, despite being very well classified (four times in the first level of priority), also came in last the same number of times. This division is reinforced in the ranking by importance, where almost half of those interviewed said they did not want to use this device to customise their houses.

During the selection and prioritisation of devices, inhabitants articulated various reasons underlying their preferences. From these responses, four key criteria were identified: (1) immersion (often described by participants as realism) and stimulation; (2) accessibility; (3) mobility; and (4) screen size. Those who ranked Head-Mounted Displays (HMDs) highest cited their immersive qualities, emphasising the enhanced realism, the feeling of being "inside" the design, and the improved perception of spatial scale. In contrast, preferences for smartphones, tablets, and computers were primarily driven by ease of access. Interviewees who prioritised these devices expressed reluctance toward using digital tables and HMDs, noting that such equipment is typically restricted to face-to-face

meetings and citing their limited accessibility for domestic use. Respondents favouring smartphones and tablets valued their mobility, whereas those who preferred digital tables and computers highlighted the advantage of their larger display screens.

The computer, particularly in the case of laptops, offers a degree of mobility and is widely accessible, as all respondents reported regular use in their daily activities. It also provides a reasonably large display, making it suitable for visual engagement. Although the experience afforded by a computer lacks the full immersion of a Head-Mounted Display (HMD), it nonetheless enables a meaningful sense of spatial presence. Through interactive 3D models and walk-through navigation modes, users can effectively simulate being within the design environment, thereby facilitating a more natural understanding of the spatial configuration.

3.6 Findings

This sub-chapter presents the main findings identified from the results of the interviews. Such insights are structured in three main groups of findings: (1) findings about the involvement of end-users in the design process for the customisation of houses; (2) findings about how inhabitants must contribute to the design; and (3) findings about how digital technologies enhance the co-design of houses. These findings relate to both groups of interviews (see sections 3.3.3, 3.4.3, and 3.5.3) and **validate the need for a user-friendly digital interface for the co-design of houses**. The interviews also supported **the identification of the users' needs for the graphical user interface proposed**, which are explained at the end of this sub-chapter.

1. **Involvement of end-users in the design process for the customisation of houses**

- Through the interviews with professionals and with housing cooperatives, it was found that there are **few cases of the practice of participatory processes** in collective housing. When they exist, they are limited to a low level of participation. In housing cooperatives, inhabitants are involved in phases that do not influence the design of the housing layout.
- Although inhabitants are not involved in the design phase, the interviews with inhabitants showed that **they would like to participate more actively in the decisions** about their living environments. However, the cooperatives representatives noted that they do not take bottom-up initiatives, nor do they always participate when having the opportunity, giving the perception that they do not have an interest. According to this fact, there are reports in the literature that the participants' attitude is considered a barrier in most collaborative approaches (Contreras-Espinosa *et al.*, 2023). Professionals say that inhabitants are interested in participating when they feel they are heard and have influence, essentially when the project directly affects them, as their houses.

- Interviews with inhabitants and housing cooperatives also showed that there is a **communication gap between cooperatives and their members** since, while inhabitants have this interest, the cooperatives do not have this perception. Inhabitants need to be better supported both in terms of communication and the way they contribute to the design. In terms of communication, as stated by Luck (2007), the goals and roles in the discussion must be clear to overcome this communication gap.

2. How inhabitants must contribute to the design

- The second phase of the interviews with inhabitants showed that there is a need to provide them with the tools to play an active role in the design definition. Therefore, more collaborative approaches need to be held, e.g., **involving the inhabitants individually in the design definition of their houses**, instead of a voting system. The literature shows that allowing inhabitants to collaborate in the design definition creates a feeling of belonging and satisfaction (Ammar, Hj Ali and Yusof, 2013).
- Some professionals suggested **involving inhabitants in hands-on activities**. Inhabitants also expressed interest in doing so. Accordingly, the literature suggests that making activities develop the inhabitants' creativity and allow them to identify and express their needs and desires (Brandt, Binder and Sanders, 2013).
- The interviews with professionals and with inhabitants reveal that the **inhabitants' collaboration should be based on a preliminary generated design and predefined options** so that they can translate their ideas into tangible solutions. Such an approach allows for widening horizons by presenting possibilities they might not know. Professionals suggested this as a way to balance between their freedom to customise and the regulatory limitations that are on the architects' knowledge. Although in the field of product design, the work of Franke and Hader (2014) is aligned with this finding, as the authors highlight the role of toolkits, such as product customisation options, in supporting decision-making by non-designers during the co-design process. The authors emphasise toolkits as learning instruments, able to provide design possibilities for users who do not know what they want. The toolkits can be composed of visual elements that are available for the inhabitants to choose from, combine, and create customised solutions. Sanders, Brandt and Binder (2010) state that the tools to generate solutions are 2D or 3D visual representations that can be used to make tangible things. Accordingly, Sanders and Stappers (2014) say that "generative toolkits" are those used to generate artefacts that represent ideas or wishes for future scenarios.

3. How digital technologies enhance the co-design of houses.

- **Digital technologies bring benefits to participatory and collaborative processes**, such as e.g. 3D visualisation and immediate feedback, that are paramount **for inhabitants' space perception and awareness of the consequences** of their decisions. The results of the interviews show this tendency by the fact that the inhabitants reported that 3D visualisation was the main reason for not having felt difficulties in understanding the designs shown to them. In this sense, digital technologies can be used to produce 3D digital models that provide different immersive and interactive perspectives, allowing non-architects to make informed decisions (Al-Kodmany, 2001; Salter *et al.*, 2009; Faliu *et al.*, 2018). Such a finding is also supported by the literature, e.g. Schroth, Wissen and Schmid (2006; Salter *et al.*, 2009), which demonstrates the **positive impact that 3D interactive and immersive visualisation has on the perception of space by non-experts**.
- Interviews with professionals show that **digital technologies are still little used in participatory processes**, especially for end users to produce their own proposals. Even so, it was found that **professionals recognise the potential of using digital tools**. They highlight the benefits of 3D visualisation not only for the improvement of space perception but also for the **enhancement of interest and engagement**, as noted by Galassi, Petríková and Scacchi (2021). The inhabitants also mentioned having an interest in **using 3D simulation systems**.
- **Time efficiency** was also mentioned by professionals as a benefit of digital technologies, since e.g., generative design can create a wide range of solutions in a short amount of time (Tomić, Krasic and Kocić, 2023). Such automation allows for finding solutions aligned with the diversity of end-users' needs, and also incorporates technical knowledge, with e.g., a **digital assistant trained based on the architects' definition of constraints and possibilities**.
- According to the interviews with housing cooperatives and inhabitants, it was found that **the potential users (people who join housing cooperatives in the future) are young people, between 25 and 45 years old, without difficulties in using digital tools** since technologies are increasingly becoming integrated into our daily lives. To avoid usability issues, the aim is to design an easy-to-use interface that allows users to interact naturally with the design process, without having to learn how to handle it.

Based on these findings, one can say that digital technologies' visualisation and automation capabilities bring benefits to housing co-design processes, such as (1) fostering interest (with playful 3D simulation systems), (2) improving the understanding of space by non-designers (providing different perspectives), and (3) addressing the diversity of user requirements and improving their understanding of design possibilities (with the automatic generation of different solutions). However, some authors state that technologies can be a barrier due to factors such as a lack of access and usability (Contreras-

Espinosa *et al.*, 2023). To overcome this barrier, this thesis argues that accessible, easy-to-use interfaces must be developed, and thus, the requirements for such interface developments should be clear.

In conclusion, despite considering it a complex process, **professionals recognise that participation is necessary, that inhabitants have an interest in participating, and that digital technologies are beneficial for participatory processes**. Thus, it would be positive to use a digital interface to allow end-users to create their own design proposals while the architects, the holders of the technical knowledge, define the limitations and design possibilities. An online tool would facilitate simultaneous engagement of multiple users, each contributing to the design of their respective residential units, to collaboratively design the same environment, i.e., a collective housing building, overcoming geographical barriers and agenda incompatibilities.

Regarding the **identification of the users' needs for the graphical user interface proposed**, the third phase of the interviews with inhabitants (sub-section 3.5.2.3), drew **insights about the features, types of visualisation and interaction, and devices.** Based on the results, it was found that:

- **Features:** it is relevant to include in the design definition process **all the features presented to the interviewees**, prioritising the options that were best classified in the ranks.
- **Type of interaction: Different types of interaction** can be used in different types of tasks, as in some tasks, a certain type of interaction may be more natural. Section 4.4, explains the type of interaction defined for each part of the interface. The **"Drag and drop"** option is prioritised, as it earned the first place in two ranks, however, **"Click on images or buttons"** can also be used.
- **Type of visualisation**: **combining the detailed drawings with the interactive 3D model** would be the best option for the inhabitants to fully understand the space and the consequences of their design choices.
- **Devices**: the **computer** is the best option to support the interface proposed, as it meets the criteria used by the inhabitants for their choices. Furthermore, the tool is intended to be naturally used by potential users who have demonstrated a preference for this device.

CHAPTER 4: Housing Co-Design: a graphical user interface for inhabitants to co-design their houses

This chapter presents the first steps of development of a Graphical User Interface (GUI) designed to facilitate end-user interaction with the architectural design process. This thesis proposes a co-design system based on generative design for housing customisation. The term 'customisation' is referred grounded in Schade's definition, which refers to the direct end-user input, while personalisation is based on data collected to deliver tailored solutions without end-user input (Schade, 2016). This thesis refers to housing customisation as the end-users are involved to make decisions themselves and configure the design of the space to adapt it to their needs.

Emphasis is placed on the user experience of a graphical user interface to be used by inhabitants in housing cooperative developments, through participatory and collaborative processes where end-users are identified before construction and thus can be involved in the design definition of their houses. Nonetheless, this does not invalidate houses from being adaptable through approaches that involve flexible construction processes such as open building and incremental housing, enabling their adaptation over time, as presented in Chapter 2. Although the proposed interface is described within a housing cooperative context, specifically for collective housing such as apartment buildings, its application is not limited to this context. The tool is intended for broader implementation, including public housing initiatives and the design of housing complexes comprising individual houses.

This work focuses on the interface, which bridges the user and the underlying design logic. It conceptualises a user-friendly interface that integrates future inhabitants in the design process and empowers them to define their own living spaces. This interface enables meaningful engagement with the design of their house, through realistic representation of space and natural modes of interaction. It enables the creation of housing solutions in an informed manner, without requiring technical knowledge, thereby overcoming the gap between designers and end-users, and the inhabitants' limited architectural skills. **The design system embodies the expertise of the architect**, as designs are defined and structured according to their instructions. Accordingly, the interface connects the architect's knowledge with the perspectives and preferences of prospective residents, acting as a mediating tool between end-users and the generative system fed by the architect. The web-based approach allows for this bidirectional communication to occur asynchronously, adapting the process to the location and agenda of each person, overcoming these difficulties found in in-person participatory meetings.

This chapter includes the definition of the target users and the graphical user interface proposed. This includes steps 2, 3 and 4 of the iterative process explained in 1.3.2. The target users are explained,

along with a description of a persona and a usage scenario, in 4.1. The user requirements (step 2) are introduced in sub-chapter 4.1. Then, the features of the interface (step 3) are explained through a description of the design phases and tasks. Finally, the Graphical User Interface (step 4) is described, introducing its modes of visualisation and interaction through the interface's phases and tasks.

4.1 Target users and scenario

This research proposes the design of a graphical user interface, to facilitate housing co-design processes, that combine the architect's technical knowledge and the inhabitants' awareness about their needs and preferences. As such, regardless of the involvement of other stakeholders at some stage of the process (and not their interaction with the design tool), target users are organised into two groups:

1. **Architects**, who define the general characteristics of the design and the options available for customising the dwellings;
2. **Inhabitants**, who make decisions by combining the options according to their own needs and preferences.

This research focuses on the development of a graphical user interface for the tasks performed by inhabitants rather than for the tasks of the architect. Therefore, no further research was undertaken on the development of a generative design system, on the architect's use of such a generative design system, nor on the system interface for the architect.

The proposal is intended for future residents of housing cooperatives. Information gathered from current members of these institutions during interviews indicates that, in general, individuals tend to join between the ages of 25 and 45. Therefore, this group of potential users of the interface consists of people within that age range.

The interviews with professionals, housing cooperatives, and inhabitants, presented in chapter 3, informed the design of the interface through the elucidation of users and a usage scenario from which user requirements were derived. These interviews provided concrete insights into users' motivations, constraints, and expectations, which were analysed to construct a representative persona and a realistic interaction scenario. The findings suggest that inhabitants should be able to define their houses individually, directly manipulating the dwelling layout across its various stages, supported by pre-generated design options and predefined customisation options. Additionally, the interface should enable users to perceive spatial qualities and understand the impact of their choices through 3D visualisation, immediate visual updates to the design, and a design assistant trained by professionals. The interviews also revealed that the interface should be designed for computer screens and

incorporate natural interaction modes, such as drag-and-drop and clicking on images or buttons, and that the visualisation should combine detailed drawings with an interactive 3D model.

These findings were translated into a usage scenario that clarifies the interaction flow with the interface throughout the different stages of defining the dwelling. The persona and scenario, in turn, served as analytical tools that allowed to translate qualitative findings into explicit functional and non-functional requirements, presented in subchapter 4.2, ensuring that the resulting system remained grounded in the lived experiences and needs expressed by participants.

Aligned with user-centred design principles, the following sections present both a persona profile and an illustrative usage scenario. The persona description encompasses personal attributes and factors relevant to the context. Additionally, a scenario is provided to demonstrate how the persona will interact with the system's functionalities. This scenario represents one of many possible use cases and is focused on user tasks, excluding the underlying logic governing the application of architectural design rules and specific graphical interface elements, which have not yet been defined at this stage of development.

4.1.1 Persona

To inform the development of the interface, a user persona was constructed. Maria is a fictional character designed to represent the characteristics of a target user group, the inhabitant, derived from data collected through the user interviews.



Figure_92 Depiction of Maria, the persona defined to represent an inhabitant, a group of target end-users

Maria, aged 28, lives with her parents in Lisbon. She is seeking to acquire her house at a reduced cost and, to this end, joined an affordable housing cooperative that is initiating the development of a new apartment building.

Maria holds a university degree and works in management. Her residential aspirations include a well-illuminated office space for remote work and generous social areas to accommodate gatherings with friends.

She has a positive relationship with digital technologies and frequently uses her smartphone to check emails, connect with friends on social media, and engage in leisure activities. However, when it comes to more demanding or serious tasks, she prefers using a computer, appreciating the larger screen that allows her to view information more clearly and comfortably.

Although Maria has no prior experience with architectural projects, she is capable of understanding spatial configurations when drawings are supported by other forms of representation, such as three-dimensional models, images, or complementary explanations.

4.1.2 Usage scenario

Maria recently joined a housing cooperative. She was invited by email to attend a meeting of the cooperative members for the presentation of a new apartment building project. During the meeting, the plot of land was shown, and it was explained that thirty units could be built on that site. The cooperative's management asked interested members to register for the project using a form. Maria was interested in the location and decided to fill out the form. In addition to personal details for administrative purposes, the form included questions about the type of housing and preferred floor.

The architect uploaded to the proposed tool the general aspects of the project according to regulations and their technical expertise. These aspects include the building type (apartment building), site plan, volume and dimensions, number of floors, and number of units. Then, they defined the common areas, vertical access points, and the layout of the units within the building, including their location, area, shape, and entrance. The architect also set the parameters that determined how residents could customise their houses through the user interface.

With all aspects of the project defined, a new meeting was scheduled with the cooperative members, also attended by the architect, who presented the project and answered members' questions. During this meeting, it was explained that they would be able to define the interior of their houses using a digital tool to make customised choices. To facilitate this, the first 30 members to register for the process were given the opportunity, in order of registration, to choose the dwelling they wished to have. A link to the online platform was sent to them, which Maria accessed from her computer and signed in. Once her account was granted access to the project, Maria selected the apartment so she could begin customising her house. She was the twelfth person to register, and after the previous eleven members had made their choices, it was her turn. Thinking about her future, and as she had indicated on the form, she chose a two-bedroom apartment (T2) located on the first floor, as there were still two available to choose from.

Starting with the selection of household requirements to define the housing layout, Maria specified that she wanted two bedrooms in her house: one suite for two people and another room for one person (the system only allows her to choose up to two bedrooms, as it was the housing typology she had chosen previously). Considering the overall area of the apartment, the system suggested that the appropriate sizes for these rooms, from the predefined options for each space, were size M for two people and size S for one. Maria followed the system's recommendation and chose those sizes.

Then, she selected a small study, a small kitchen, a small bathroom, and a medium-sized living room. These sizes were also suggested by the system according to the number of people in her household.

With the requirements defined, the system generated the possible layout options and presented them to Maria, who decided on one of the options. However, she still wishes to make a small adjustment to the arrangement of the spaces. She repositions the single bedroom, placing it next to the study (Figure 93). The system warns her that this change is not possible, as it would block access to the bedroom, and suggests using a part of the study to create space for the bedroom entrance (Figure 94). Maria can either cancel the modification or accept the suggestion. She chooses to accept it and proceeds to the next stage of the layout configuration.

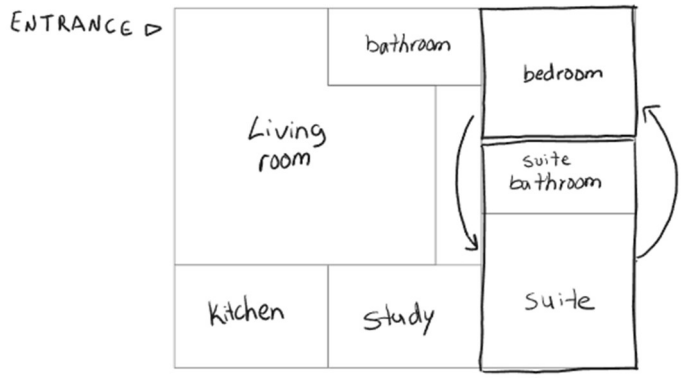


Figure 93_Change that Maria intends to make to the layout distribution.

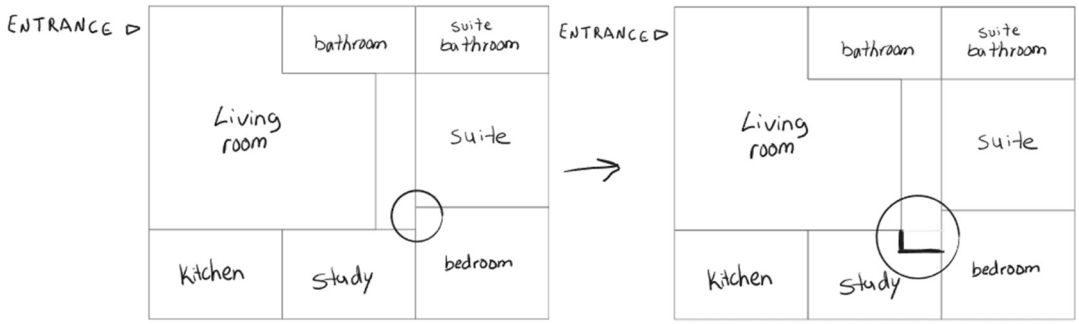


Figure 94_Left: System alert regarding access to the single bedroom; Right: System suggestion to solve the issue

In the next stage, Maria defined the connections between the rooms. She places the connection between the hallway and the bedrooms, study, and bathroom, as well as the passage from the suite to its corresponding bathroom. In the kitchen, she decided to remove the wall bordering the living room to create an open space. Maria was about to move on to the next step, but the system wouldn't let her proceed, displaying an alert that there was no access from the living room to the other areas of the house (Figure 95). She then created a connection to the hallway, and was able to move on to the next stage.

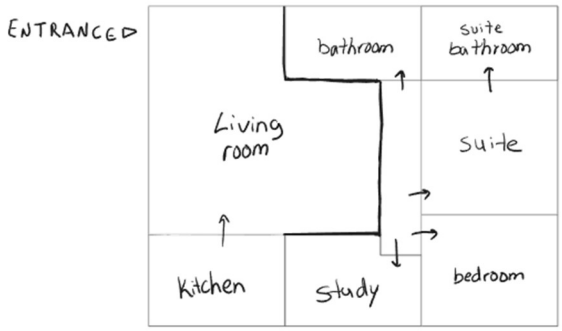


Figure 95_Connections between spaces made by Maria. Living room walls highlighted to indicate there is no passage to the other rooms

In the detailing phase, the spaces are represented with construction elements and a suggested furniture arrangement, based on the location of the entrances that Maria defined in the previous stage. The kitchen and bathrooms are editable. She chose their layout from the options presented by the system. For the kitchen, e.g, she chose a peninsula instead of the U-shaped kitchen layout presented by default (Figure 96), which was automatically updated.

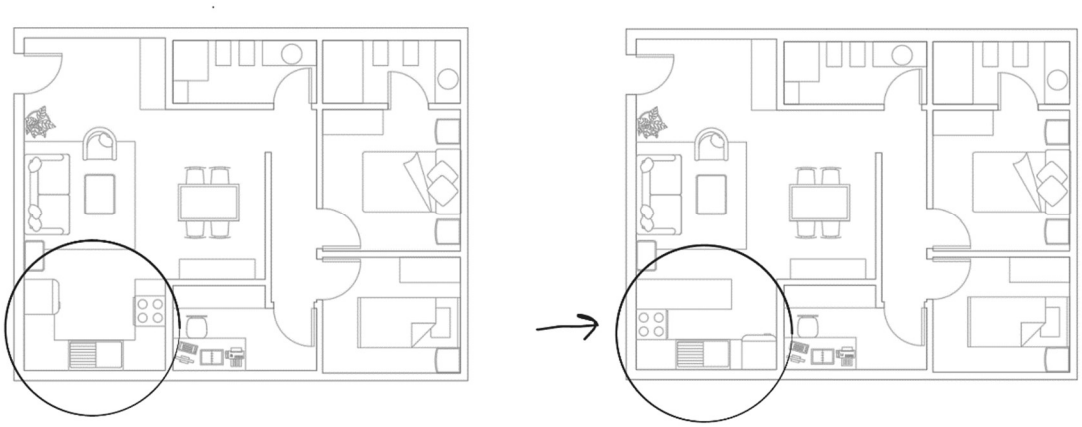


Figure 96_Kitchen layout change made by Maria

In the next phase, the finishing materials are presented by room and type. This helped her make appropriate material choices. She selected materials for the flooring, walls, kitchen cabinets and countertops, bathroom fixtures, door types, and so on. Since the materials have associated costs, the system calculated the materials budget based on the areas where Maria had assigned them.

She submitted her project, and once all the members were satisfied with the design of their houses, the drawings of the entire building were generated, in order to proceed with the structural and infrastructural specialities designs with the respective responsible technicians.

4.2 User requirements

The interface's functional requirements are the user requirements regarding the co-design process and the necessary conditions for the inhabitants to actively collaborate in the design process. These

are the features of the system. These functional requirements were defined by the results of the interviews with professionals, housing cooperatives and inhabitants.

The non-functional requirements refer to the usability aspects of the graphical user interface. These requirements were informed by the sorting technique used in the third phase of interviews with inhabitants, which generated preference rankings related to aspects of the user interface, such as types of interaction, types of visualisation and devices.

Given the findings of the interviews, and upon the definition of the persona and her usage scenario, this research considers that a digital tool that assists co-design in housing projects must comply with the following **functional requirements**:

1) **Direct contact with the design**: the interface should allow the user to make decisions about the housing design in different phases of the process, by letting them directly manipulate a digital artefact to define the space layout and its elements.
2) **Individual participation**: inhabitants should be able to individually define their houses. This approach enables a better response to each household's needs since each house is defined independently from the others.
3) **Provide a base design for the user to improve on**: the tool should produce viable design solutions that respond to the specific needs and preferences. These preliminary proposals should be generated based on requirements initially defined by the user and then presented to them to be selected and refined.
4) **Choices through predefined options**: the interface should provide toolkits composed of visual elements that represent architectural options (e.g. options for layout arrangements, kitchen configurations and types of finishing materials). Such an approach provides a simple interaction that does not require advanced or technical knowledge, as the architect provides the constraints and possibilities.
5) **Immediate feedback and decision support**: the interface should provide real-time visual feedback, allowing users to see the evolving design as they make decisions, and be informed about the consequences of their choices. A digital assistant should support this process by offering informative insights and suggesting alternative solutions when user decisions may lead to inappropriate results.
6) **Support for generative design**: the design system shall incorporate generative design methodologies to produce viable architectural proposals. It must be capable of generating alternatives based on predefined parameters (such as room dimensions categorised into small, medium, and large) and presenting these alternatives according to user-defined preferences. It should also be capable of evaluating user interactions in real-time, suggesting alternative solutions when needed.

7) **Diverse perspectives**: In addition to the floorplans, the interface should incorporate three-dimensional visualisation, enabling users to navigate and interact with a virtual model of the design space. This semi-immersive experience enhances the user's understanding of the space and design possibilities.

In addition to the functional aspects, the digital tool intended to support co-design in housing projects must consider the following **non-functional requirements**:

1. **Structured library of design options**: the tool shall include an organised library of design components, systematically categorised to facilitate user navigation and selection. These categories may encompass pre-generated layout configurations, room layout variants, dimensional options for each room and permeability elements (e.g., doors), and finishing materials. Each category must be clearly defined to support efficient retrieval and presentation.
2. **Natural interaction mechanisms**: the interface shall support drag-and-drop interaction for placing design elements within the housing layout, as well as clickable images and buttons to facilitate user input during other phases of the design process, such as the initial definition of requirements.
3. **Dual mode of visualisation**: the interface should offer a space for two simultaneous types of visual representation of the design, combining orthogonal traditional representations with the visualisation of an interactive 3D model.
4. **Device and input specifications**: the interface should be used on devices equipped with relatively large screens, such as desktop or laptop computers, with interaction through conventional input devices, including a mouse and keyboard. The interface must be responsive and adaptable to varying screen resolutions and aspect ratios.

These requirements guide the interface design. Table 28 presents the direct relationship between the user requirements and the corresponding design decisions concerning the user experience, including the features implemented and interaction and interface approaches adopted.

*Table 28 Relationship between user requirements and interface design decisions. **FR:** Functional Requirements**; NFR:** Non-Functional Requirements.*

Requirements	Design decisions
FR1: Direct contact with the design	The direct contact with the design is made by defining the house design brief and customising it. This involves features as selecting the rooms (including the addition of customised rooms), their sizes and number of occupants, choosing from automatically generated housing layouts and refining them through the direct manipulation of rooms in the floorplan representation. It also includes choosing from predefined options of different housing elements.
FR2: Individual participation	Each household is independent from other, and the inhabitant can decide the interior of their house by defining the house functional program and finishing materials.
FR3: Provide a base design for the user to improve on **and FR6**: Support for generative design	The interface presents layout solutions generated based on the room types and dimensions previously defined by the user. These options are presented in a library where the user can choose from to customise the house layout.
FR4: Choices through predefined options **and NFR1:** Structured library of options	The options (layout arrangements, types of room configurations, opening dimensions, finishing materials) are presented to user through clickable or draggable visual representations located at a library space at the bottom of the interface. These options are internally structured by categories and presented according to the phase of the house design.
FR5: Immediate feedback and decision support	Real-time visual feedback is provided through the continuous updating of both the floorplan and the 3D model following each user action. In addition, a digital assistant offers informative textual feedback and visual floorplan representation whenever user decisions lead to inappropriate outcomes, accompanied by suggestions for suitable alternatives.
FR 7: Diverse perspectives **and NFR3:** Dual mode of visualisation	The interface supports visualisation through both a detailed floorplan and an interactive 3D model. These forms of visualisation are presented simultaneously, with the main interface screen divided into two sub-screens.
NFR2: Natural interaction mechanisms	Buttons and clickable images are used to choose room types and number of occupants, manipulate the 3D view, interact with menus or toolbars through the different phases of the design process, and proceed to subsequent phases. Drag and drop is used to directly manipulate the design, such as changing the location of rooms and openings, and to assign options from the library in the different design phases. The direct manipulation also includes clicking on specific elements of the house design to select them.
NFR4: Device and input specifications	The interface is designed for devices equipped with relatively large screen such as desktops and laptops, with horizontal aspect ratio.

The following **data requirements** must also be considered. Although they do not directly define the graphical user interface for the inhabitant, they provide contextual information on which data is presented:

1. **Input data:** The system must allow the introduction by design experts of the design rules for the generation of the different layout and customisation options, that are structurally saved to be later retrieved and presented to the user. Also, the materials options should include options from real suppliers for each type of finishing material, including their reference, price and representative images of their application.
2. **Output data:** The tool must generate as output the detailed floorplan and 3D views of the resulting customised design, as well as the budget resulting from the calculation of materials price and the assigned areas.

4.3 Design Phases and Tasks (allocation of functions)

This section introduces the features of the system, which match the design tasks carried out by the persona through the graphical user interface. Considering the outlined user requirements extracted from the interviews, a framework was defined for the co-design of housing. Although the focus is on the user interface for the inhabitant persona, it was suitable at this phase to consider the whole framework for context.

The proposed system encompasses tasks carried out by three different entities, where two of them are personas, and the other is the system itself, depending on the design phase (Figure 97): the architect persona (at an initial phase), the system (which automatically performs certain tasks without human intervention), and the inhabitant persona (assisted by the system).

Although the interviews indicated a priority list for the features, all of them were considered and the tasks were arranged according to the sequence of a standard design definition process, as found in the design systems documented in the literature and also illustrated in the defined usage scenario. The tasks must be performed in the order described below, as each stage depends on the output produced in the preceding phase.

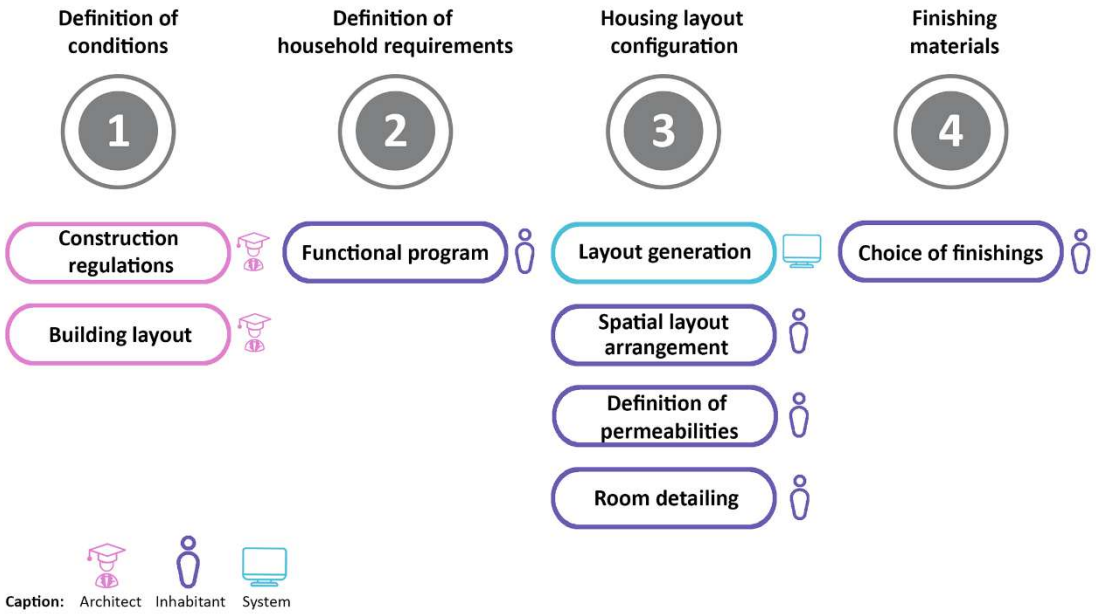


Figure 97_Phases (1, 2, 3, 4) and tasks of the housing definition process

The first phase refers to the "**Definition of conditions**". This phase includes the "Construction regulations" and "Building layout" tasks, which are both performed by the architect. In "Building layout", the architect's task is to define all the general characteristics of the building and construction process. Such characteristics include the number of floors, height, shared spaces, vertical access points, housing units' shape configuration and distribution, energy efficiency of the building, type of

construction system, etc. If the project involves single-family houses, the architect can decide to leave the location and shape of the houses for inhabitants to define, depending on the conditions. “Construction regulations” refer to the design rules defined by the architect and the conditions that will assist inhabitants’ decisions regarding the interior of their houses in subsequent phases. Such conditions are based on the architect’s knowledge and experience, as in Habraken’s Supports method, as well as the local regulations. The regulatory requirements are met through the generative system that is fed by the architect.

In the “**Definition of household requirements**” phase, Maria defines the functional program, deciding which spaces are needed and their overall area. Maria defines the number of each type of space and then their dimensions based on predefined options. She starts by choosing the number of occupants for each space, and the system presents different corresponding sizes (S/M/L) for her to choose.

In the “**Housing layout configuration**” stage the interior layout of each house is defined. This phase encompasses four tasks performed by Maria and the system, in different assignments: a) layout generation; b) spatial layout arrangement; c) definition of permeabilities; d) room detailing.

The system performs the "Layout generation” task automatically. The floor plan is generated based on the requirements defined by Maria and the conditions defined by the architect in the previous phases.

Maria performs the remaining three tasks. In the “Spatial layout arrangement” task, Maria makes decisions concerning the spatial arrangement of the dwelling, supported by the system. The system presents the options that best fit her requirements, and she can choose one to proceed with the customisation. If she is not satisfied with the housing layout, she can reorganise the rooms that were initially presented. This adjustment is supported by the system, which warns her if an action would result in an inappropriate design and gives suggestions, according to the regulations and conditions initially defined by the architect.

In the “Definition of permeabilities” task, Maria may accept the connections between rooms that are assigned by default or redefine them, including their location and size. She can also remove partitions between spaces to join them. Only walls free of structural or infrastructural elements can be removed. This is supported by the system, which blocks access to the next step until all areas have defined connections.

In the “room detailing” task, the system generates and presents a detailed plan with furniture symbolic representation for Maria to understand the rooms’ size better. Furthermore, to ensure greater satisfaction with bathrooms and kitchens (rooms where future changes can be very costly), Maria can edit these elements from predefined options presented, which were generated by the system according to the permeabilities defined in the previous task.

The phase of "**Finishing Materials**" includes the task "choice of finishings", which is performed by Maria. In this task, she chooses the finishing materials for the different housing elements such as flooring, wall coverings, door types, kitchen cabinets and countertops, bathroom fixtures, etc. The materials' predefined options are categorised and presented to her from a library of products from suppliers, with associated costs. The system calculates the cost of the house's finishings based on the chosen materials and the area where it has been applied.

Maria may, at any point, adjust the requirements and revise her decisions to explore alternative solutions.

As mentioned before, this research focuses on the development of a graphical user interface for the tasks performed by inhabitants rather than for the architect's tasks. Furthermore, the interface proposed focuses on the user experience and, therefore, must be easy to use, without the need for any technical knowledge from the user. For this reason, the system must assist the user throughout the process. Thus, this thesis proposes that a design system must automatically generate viable housing solutions based on user requirements and provide predefined options for users to choose and customise their house layouts through the proposed graphical user interface. Besides, the system needs to display warnings when the user performs actions that result in solutions that do not comply with regulations.

4.4 Graphical user interface: Interaction and visualisation

This section introduces the first version of the Graphical User Interface (GUI), which was designed and prototyped to be tested with potential users. As shown in (Figure 98), the GUI contains three main areas: 1) a top horizontal toolbar with the design phases and generic buttons (e.g., save, undo/redo, close); 2) the main screen, divided into two sub-screens where the interaction with the design and their visualisation is made; and 3) a bottom horizontal bar corresponding to the library where the predefined options are displayed.

Although technical terminology was used to identify the design phases and tasks in this thesis, common terminology is used in the interface to respect the second Nielsen's heuristic (Nielsen, 1994a) "Match between the system and the real world" by using the user's language. Also, the interface was designed in Portuguese, since it would be tested with a Portuguese audience.

Table 29 shows how the design phases and tasks are identified in the interface. The phase "definition of household requirements" is identified in the interface as "Requirements". In this phase, the task "Functional program" corresponds to "Quantity and dimensions of rooms".

The design phase "Housing layout configuration" is identified in the interface as "Organisation". Within this phase, the task "Spatial layout arrangement" corresponds to "Room's organisation"; the

task “Definition of permeabilities” corresponds to “Connections and passages”; and the task “Room detailing” corresponds to “Detailing”.

The design phase “Finishing materials” is presented in the interface as “Materials”, with the task “Choice of finishings” corresponding to “Choice of materials” .

Table 29_Correspondence of the thesis and the interface terminology of design phases and tasks: Thesis’ terminology highlighted in light grey and Interface’s terminology below in Portuguese (grey text) and English (black text)

<table>
<tr><th colspan="3">Phase</th></tr>
<tr><td>Definition of household requirements</td><td>Housing layout configuration</td><td>Finishing materials</td></tr>
<tr><td>Requirements
Requisitos</td><td>Organisation
Organização</td><td>Materials
Materiais</td></tr>
<tr><th colspan="3">Task(s)</th></tr>
<tr><td>Functional program</td><td>Spatial layout arrangement</td><td>Choice of finishings</td></tr>
<tr><td rowspan="5">Quantity and dimensions of rooms
Quantidade e dimensões das divisões</td><td>Room’s organisation
Organização das divisões</td><td rowspan="5">Choice of materials
Escolha de materiais</td></tr>
<tr><td>Definition of permeabilities</td></tr>
<tr><td>Connections and passages
Ligações e passagens</td></tr>
<tr><td>Room detailing</td></tr>
<tr><td>Detailing
Pormenorização</td></tr>
</table>

The design phases are tracked in the top toolbar, and the current phase is highlighted to ensure Maria’s awareness of the process. On the right corner of the bottom toolbar, there are also buttons for her to change to the next and previous phases (e.g., Figure 100). Throughout the entire design process, the interface provides instruction sentences to guide the user on what to do at each phase. These instructions appear on the main screen (Figure 98) and in the library, according to where Maria needs to interact to perform the next step of the task. The main screen has right and left sub-screens, which display different features according to the task. The interaction in this workspace is made by clicking buttons and dragging icons from the library.

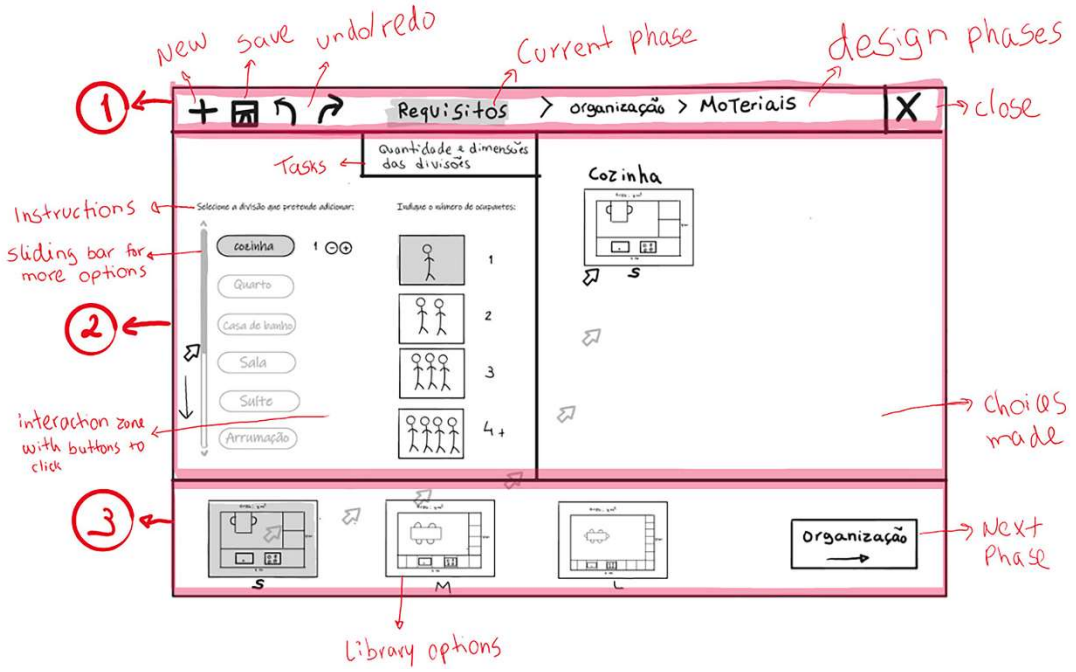


Figure 98_Sketch of the user interface showing the task "Functional program" ("Quantity and dimensions of rooms"/ "Quantidade e dimensões das divisões" within the definition of household requirements ("Requirements" / "Requisitos") phase. The three main areas are highlighted: 1- top toolbar; 2-main screen; 3- library bar.

In the "**Definition of the household requirements**" ("Requirements") phase (Figure 98), Maria performs the task "Functional program" ("Quantity and dimensions of rooms"). In this task, Maria interacts with the left sub-screen to select room types and specify the number of occupants. The process begins with the selection of a room type, followed by the choice of occupant number from predefined options, through clickable images. For common areas, the number of occupants is fixed to match the total predefined number of household members. For each selected room, the system presents size options within the library. These options are S/M/L, as Maria may not have a clear perception of areas or dimensions. The room size options are displayed according to the selected number of occupants, and the "S" size corresponds to the minimum regulatory dimensions required for that specific room type.

For choosing a size option for the room, Maria can drag it to the right sub-screen. This area serves as a workspace where selections are recorded and visually displayed (see Figure 98). In subsequent phases, where a housing layout is visually presented, the left sub-screen displays the floor plan, while the right sub-screen presents a three-dimensional representation of the dwelling (see, for example, Figure 100).

In the left sub-screen, the room types selected are highlighted and repositioned at the top of the list, and Maria can add multiple instances of the same room type, such as bedrooms, or remove them using "+" and "–" buttons. Additionally, she may introduce a customised room not included in the predefined list by selecting the corresponding option at the bottom and typing a name (Figure 99).

After choosing the number of occupants, the system presents an empty space representation for Maria to choose their size, whereas the options for the predefined room types are represented with a symbolic furniture arrangement. To proceed to the next phase, at least one bedroom, kitchen, living room and bathroom must be selected.

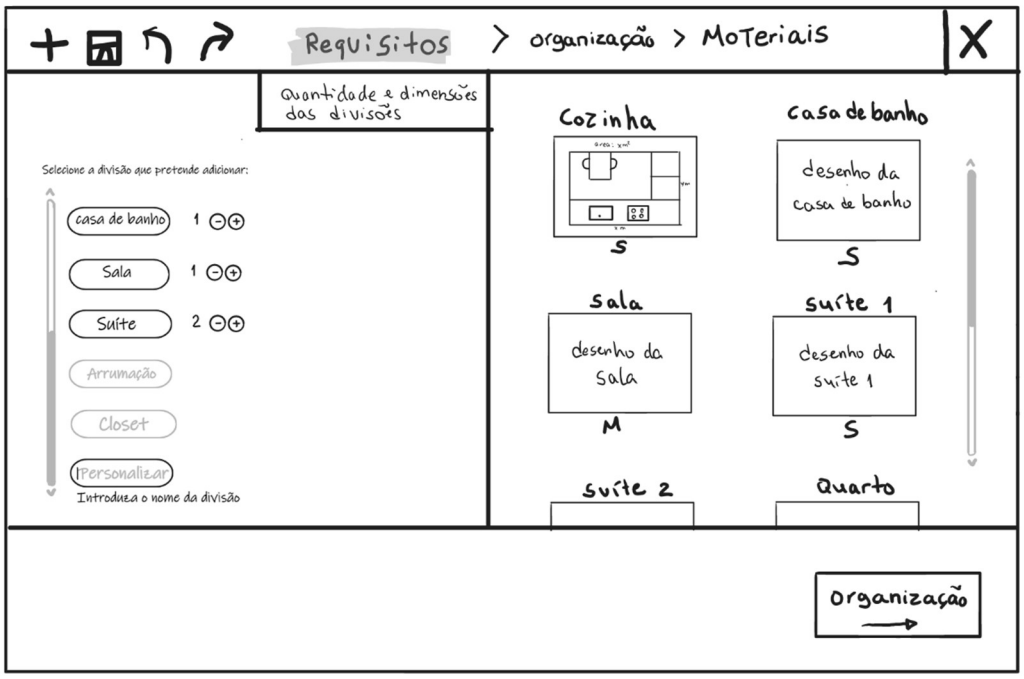


Figure 99_Sketch of the user interface for the task "Functional program" ("Quantity and dimensions of rooms"/ "Quantidade e dimensões das divisões" showing the option for adding a customised room (left sub-screen)

Proceeding to the next phase, Maria accesses the "**Housing layout configuration**" ("Organisation") phase, where three tasks are performed: "Spatial layout arrangement", "Definition of permeabilities", and "Room detailing". In the "Spatial layout arrangement" task ("Room's organisation"), Maria starts by choosing one of the house layout options available in the library, dragging it to the left sub-screen. The system generates these options based on the requirements defined in the previous phase. The option chosen is displayed in the left sub-screen of the interface in a floorplan representation, while the right sub-screen displays the 3D representation (Figure 100).

The right sub-screen also holds a side interaction menu for Maria to manipulate the 3D view. The options include interactions often found in 3D modelling environments, such as (from the bottom to the top) zoom out, zoom in, camera rotation to the left, to the right, to the bottom, to the top, pan (repositioning the viewport by moving the view of the model horizontally or vertically without altering the zoom level or perspective), hide/unhide (used to temporarily hide elements of the 3D model), and refresh (used to return to the initial perspective of the 3D model). The interface also allows for keyboard and mouse shortcuts for these interactions, complying with the seventh Nielsen's heuristic

"Flexibility and Efficiency of Use" (Nielsen, 1994), which refers to adapting the interface to different levels of users, such as novice and expert users.

After choosing the layout, Maria can also customise the design by changing the position of the rooms. To do so, she drags them on the floorplan (left sub-screen). When Maria changes the design, the system automatically updates both representations, and she sees the results of their choices.

As mentioned before, the system assists Maria in this task by evaluating her actions and warning her if they would result in a design that does not comply with regulations. The warning appears as a pop-up message in the centre of the screen, graphically showing the issue and explaining it through text, and suggesting a feasible solution that Maria can accept, generate another solution, or choose to cancel the change in the design (Figure 101).

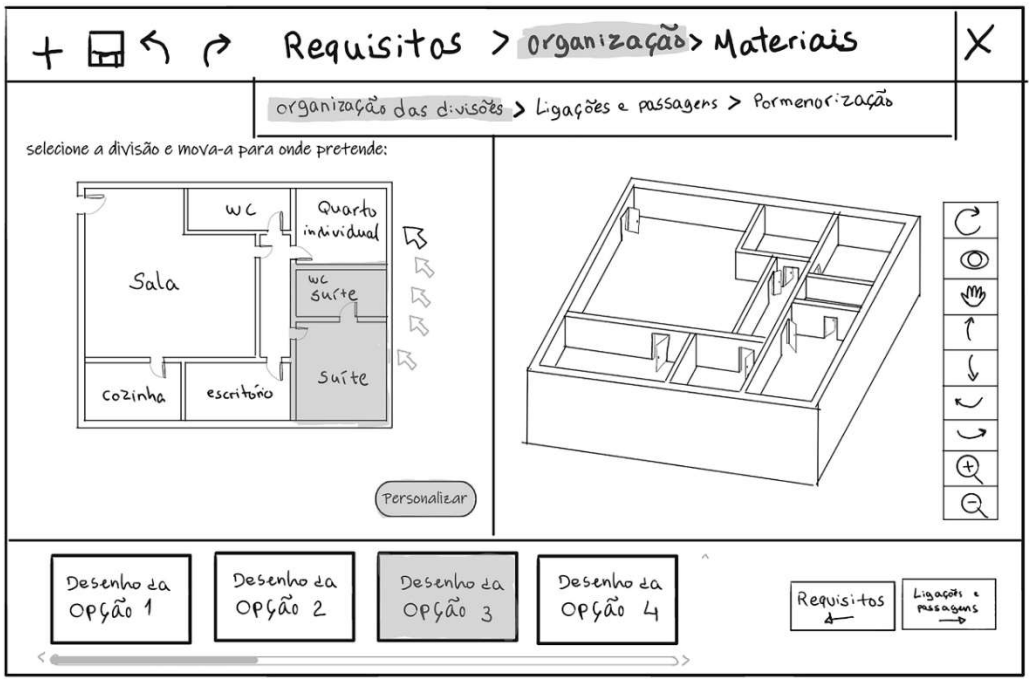


Figure 100_Sketch of the user interface showing the task "Spatial layout arrangement" ("Room's organisation"/ "Organização das divisões") within the housing layout configuration ("Organisation"/ "Organização") phase, with rooms being dragged in the floorplan (left sub-screen) and the 3D representation on the right sub-screen

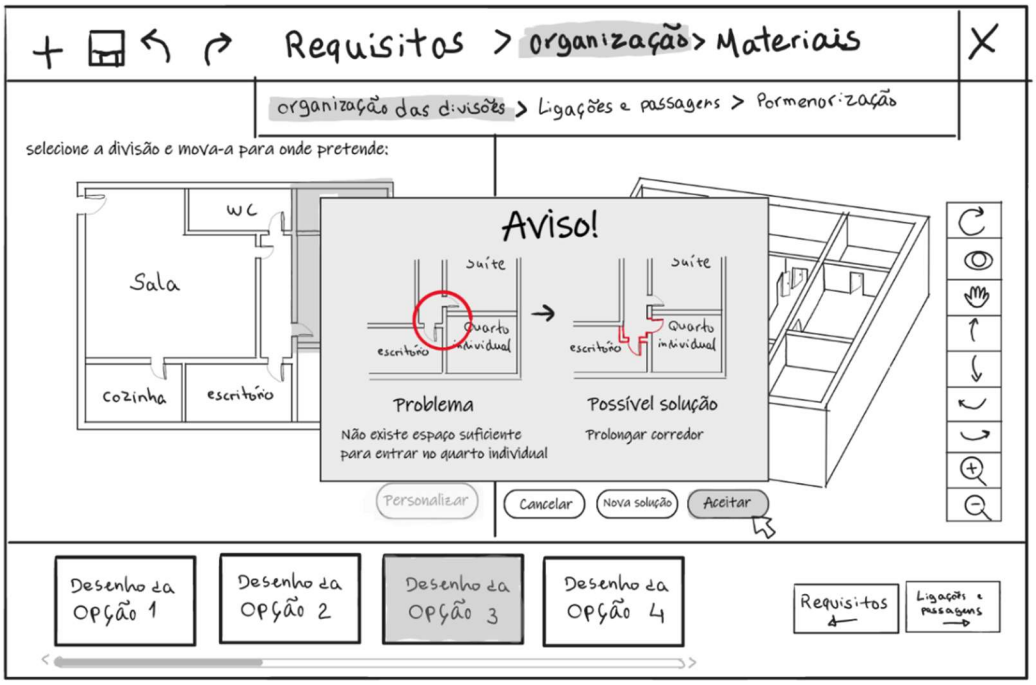


Figure 101_Sketch of the user interface showing the task "Spatial layout arrangement" ("Room's organisation"/ "Organização das divisões") showing the system's warning regarding an issue in a user-driven room rearrangement with an alternative solution

The next task, "Definition of permeabilities" ("Connections and passages"), allows Maria to edit the connections between rooms. The design of the dwelling is displayed with walls rendered in a faded style, while doors are emphasised using darker outlines to enhance visual distinction. By default, the system assigns passages between spaces, whose positions can be reconfigured by dragging them to the desired location. Other options are available in a pop-up menu, that appears by clicking the opening, which offers options to modify the door's opening direction or to remove it entirely (Figure 102). Maria can also change the dimension of the opening by choosing it from the library and dragging it into the design. The predefined options are S/M/L. If Maria wants to join two rooms by removing an entire wall (not structural or those related to the dwelling's infrastructure), she selects the option "total" in the library to activate this feature. Then select the wall she wants to remove, and an "X" button appears to confirm the elimination (Figure 103).

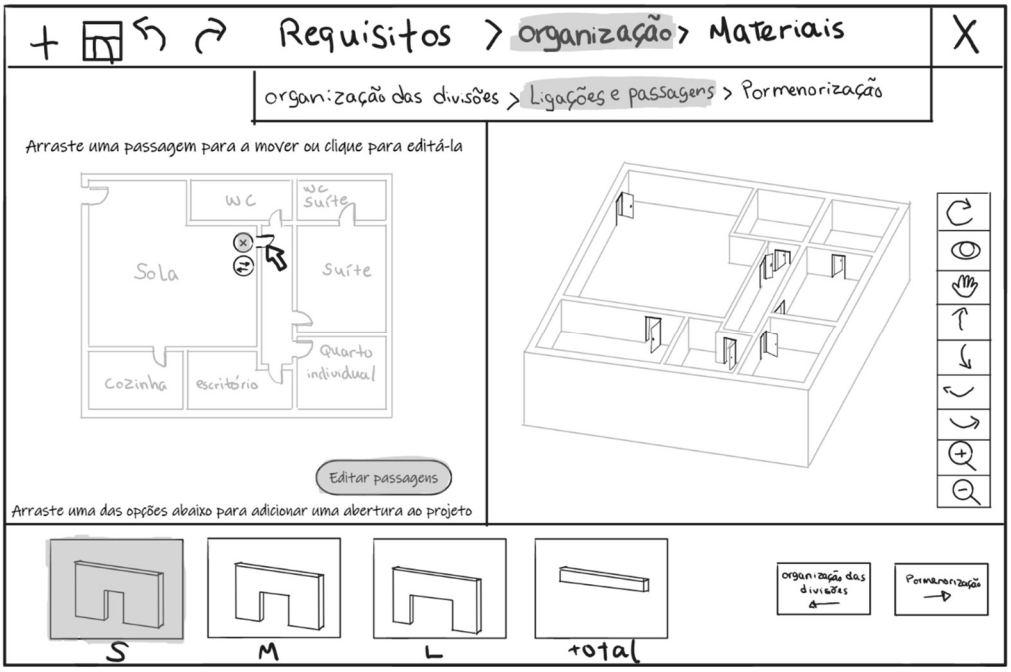


Figure 102_Sketch of the user interface showing the task "Definition of permeabilities" ("Connections and passages"/"Ligações e passagens"): A S-sized door is selected, and a pop-up menu with options to change or delete it is visible.

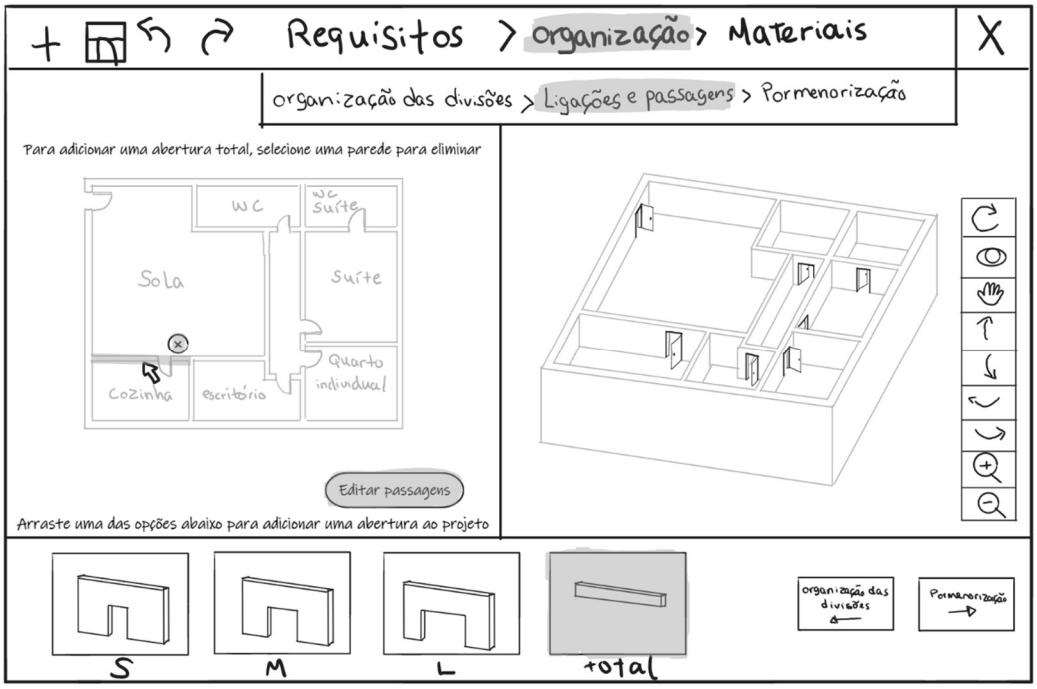


Figure 103_Sketch of the user interface showing the task "Definition of permeabilities" ("Connections and passages"/"Ligações e passagens") with the library option "total" activated and a wall selected to be removed

In the "Room detailing" ("Detailing") task, a detailed floorplan and 3D representation are shown with symbolic furniture arrangement for Maria to better understand the rooms' size. The selectable rooms (kitchen and bathrooms) are highlighted while hovering the cursor. Maria selects in the floorplan the kitchen or the bathroom she wants to define, and the system presents the library's

different options for the type of room selected. The chosen option is dragged into the design (Figure 104). Whenever she is satisfied with the kitchen and bathroom layouts, she can proceed to the next phase.

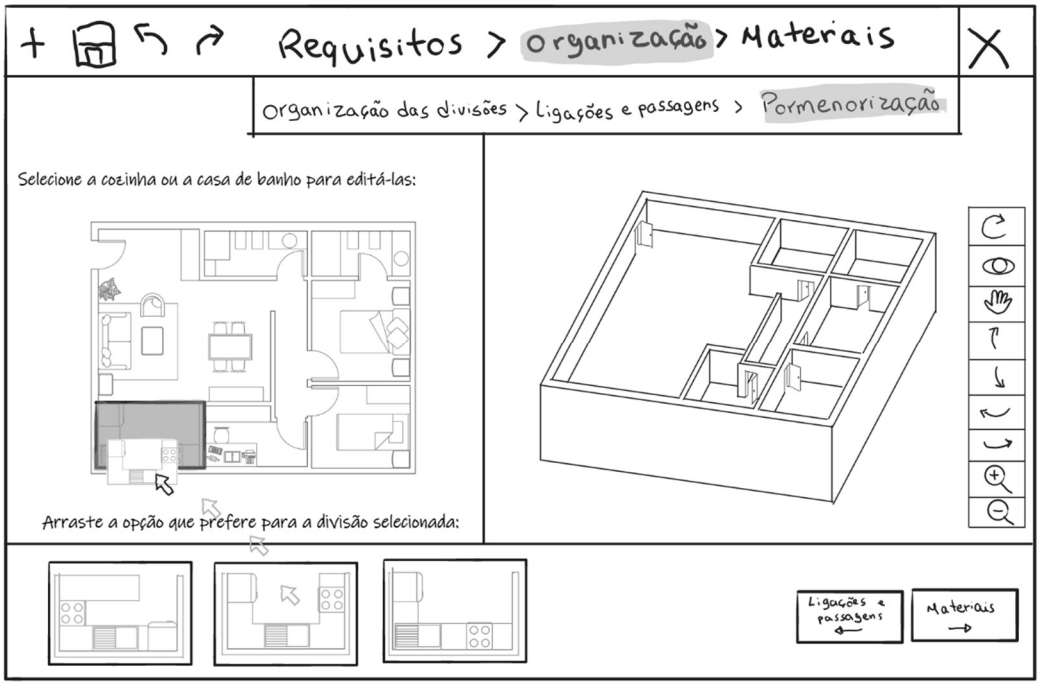


Figure 104_Sketch of the user interface showing the task "Room detailing" ("Detailing"/"Pormenorização") with a kitchen library option being dragged into the design to replace the kitchen layout assigned by default.

In the "**Finishing materials**" ("Materials") phase, Maria performs the task "Choice of finishings" ("Choice of materials"). In the left sub-screen, Maria selects the button corresponding to the element of the house she wants to assign a finishing material to. The system presents in the library the types of materials corresponding to the element chosen, which can be dragged and placed in the desired room on the floorplan. Figure 105 shows an example of wooden flooring assigned to the living room floor. Different options of flooring are shown in the library, and the highlighted option is the one assigned to the living room. When Maria is satisfied with the materials assigned to all elements of the house, she can submit the design of her house in the button placed at the bottom left corner, and the system then calculates the budget based on room areas and chosen materials.

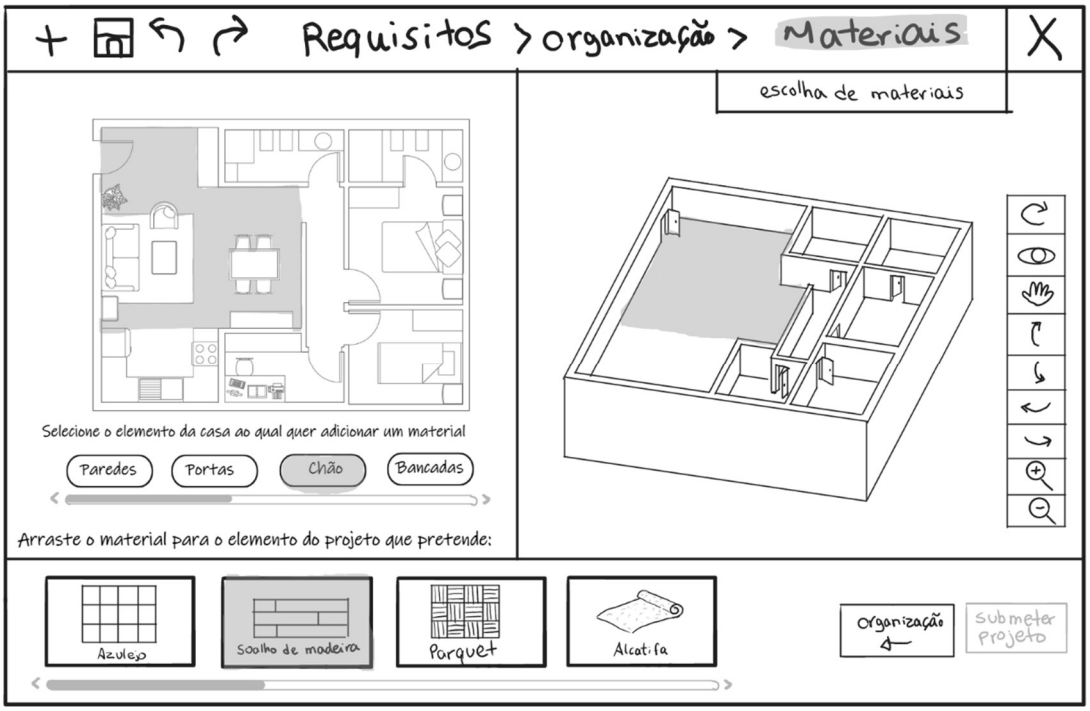


Figure 105_Sketch of the user interface showing the task "Choice of finishings" ("Choice of materials"/ "Escolha de materiais"), within the finishing materials ("Materials"/ "Materiais") phase, with a wooden flooring assigned to the living room floor

CHAPTER 5: Prototyping and evaluation

This chapter presents the iterative process through which the graphical user interface was assessed and progressively refined, in direct alignment with the methodological steps outlined in 1.3.2.

It begins with a formative evaluation of a low-fidelity prototype (step 5) in sub-chapter 5.1, followed by the subsequent refinement of the interface based on user feedback (step 6) in sub-chapter 5.2.

The chapter then details the development of a high-fidelity prototype and its evaluation through multiple stages in 5.3, including a heuristic assessment conducted by usability experts (step 7, section 5.3.1), which informed a further refinement of the interface (step 8, section 5.3.25.3.2).

This was complemented by a summative evaluation with end users (step 9, section 5.3.3), and finally by a discussion with architects (step 10, section 5.3.4), who engaged with the tool both as end users and as professionals, offering critical insights into its strengths, limitations, and relevance to architectural practice.

Finally, the chapter presents the findings gathered from successive cycles of testing and refinement, which ensured that the development process remained firmly grounded in the user-centred methodology established at the outset.

5.1 Formative user evaluation using a low-fidelity prototype

Formative usability and task satisfaction tests were carried out to assess the interface presented in Chapter 4. A low-fidelity paper prototype was used as the second iteration of the interface development (see Figure 3). This evaluation aimed to identify problems and opportunities for improving the interface. Participants were assigned tasks to perform using the interface. Afterwards, they completed three questionnaires assessing its usability and their task satisfaction and provided narrative feedback on its positive and negative aspects.

The tests were conducted with five participants, since the literature recommends using this number of evaluators (Nielsen, 1994d, 2000; Gonçalves, Fonseca and Campos, 2017). Nielsen (1992) found that while five usability specialists can find 85% of usability problems in heuristic evaluations, more than 15 novice evaluators would be needed to find this percentage of problems. However, the author (Nielsen, 2000) recommends multiple rounds of testing with small groups of **five potential users** rather than one large test with 15 users, especially **during formative usability testing**, since at this phase, the goal is to conduct quick and cost-effective evaluations.

The participants were selected through contact with the inhabitants of housing cooperatives that had participated previously in the interviews. Some of them had previously expressed an interest in

participating in the interface evaluation when they were asked during the interviews if they would like to be contacted again to see the result of the work developed after the interview in which they participated. These inhabitants agreed to participate in the experience and signed a written consent form. The remaining were suggested by these inhabitants, through snowball sampling, with the criteria of being between 25 and 45 years old, even if they were not inhabitants of housing cooperatives and gender was not controlled. This age range was identified during the interviews as the age of the potential users of the interface, since people join housing cooperatives at this age, and are more willing to take part of the definition process of their houses. The recruitment was made between October 13th 2022 and October 25th 2022.

A preliminary demographic questionnaire was applied before the experience. According to the collected data (Table 30), two participants were between 25 and 30 years old, and two were between 31 and 35 years old. Three males and two females participated. Two of them reported having a fair relationship with digital technologies, and three said they have a very good relationship. Three participants had previous contact with architectural projects, while two participants had not. All respondents said they were motivated to participate in the experience.

Table 30_Results of the demographic questionnaire applied at the formative evaluation

Inhabitant	I1	I2	I3	I4	I5
Age					
25-30	x	x		x	
31-35			x		x
35-40					
40-45					
Gender					
Male	x	x		x	
Female			x		x
Other (specify)					
Relationship with digital technologies					
Very poor					
Poor					
Fair			x		x
Good					
Very good	x	x		x	
Prior contact with architectural projects					
Yes	x	x	x		
No				x	x
Feeling					
Motivated	x	x	x	x	x
Apprehensive					
Other (specify)					

A paper prototype was created representing the general layout of the interface and paper pieces corresponding to the buttons, the library's options, and the housing design's 2D and 3D representations. These pieces were attached to the interface layout and could be moved or replaced during the tasks' performance to simulate the system feedback to participants' actions (Figure 106).

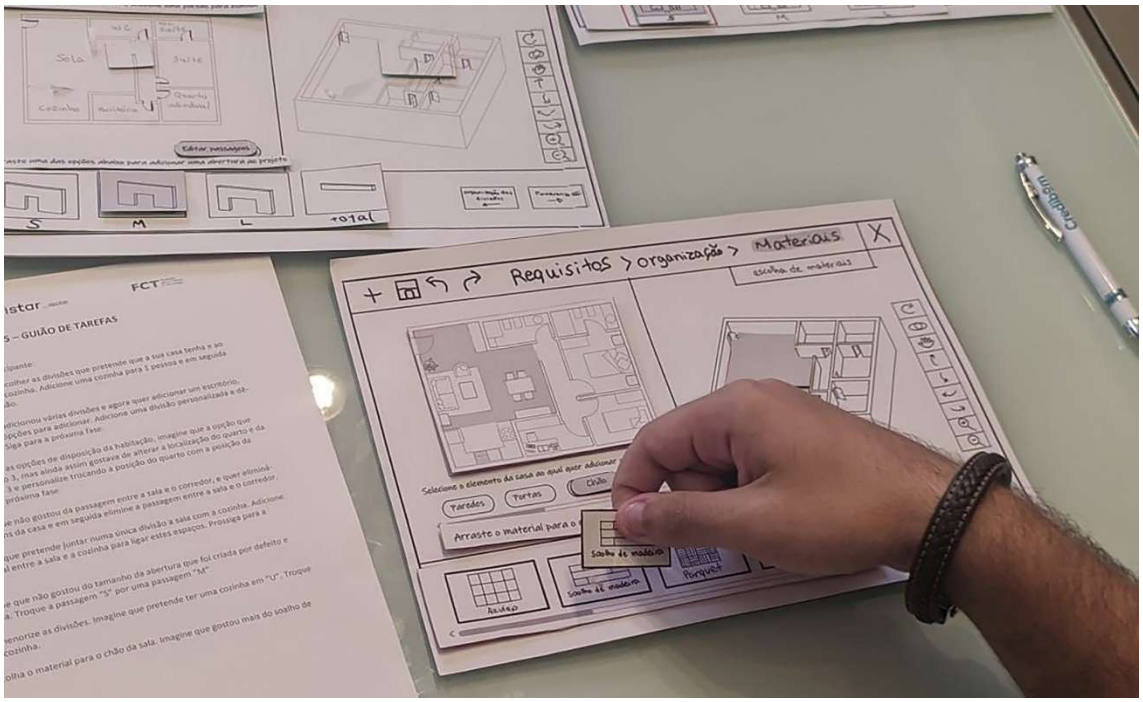


Figure 106_Paper prototype with pieces being moved during the formative evaluation with inhabitants

All participants performed eight tasks to experience the different interface features along the design phases, in a within-design user study. They were asked to follow a script with various tasks, since the prototype was only developed for some specific scenarios and not for all possible scenarios. Participants were asked to imagine that the indicated choices would be their preferences. The protocol of the formative evaluation is provided in Appendix B, which includes the task script given to the participants to guide them in the interface experimentation, the required steps for each task (which were not given to participants), the questionnaires applied, and the materials used for the paper prototype.

Task 1 consisted of selecting a room and its size in the definition of household requirements. Task 2 was intended to add a customised room that was not on the list of rooms available to choose from. Task 3 aimed for the participants to choose one of the library options for the housing layout and then customise it by swapping the position of two rooms. In task 4, the participants should remove a connection between rooms. In task 5, they should remove a wall to connect two rooms. Task 6 was intended to replace a connection with one of a different size from the original. Task 7 consisted of detailing the floorplan by choosing the kitchen layout. Finally, in task 8, the participants should choose a flooring material and assign it to a room.

The independent variables of the study are the participants' age (between 25-45 years old), the script of tasks, and the interface design media presented to the participants. In this study, this last variable was controlled and set to a low-fidelity paper prototype. These variables were controlled to ensure that all participants were exposed to the same conditions. The dependent variables are the

measured results affected by the experimental condition, namely, usability, task satisfaction, and task performance measures (such as efficacy, efficiency, and number of attempts). Qualitative participants' opinions regarding the best and worst aspects of the interface were also collected.

During and after the experience, the participants answered three questionnaires regarding the dependent variables: SEQ (Single Ease Question), a single question that assesses the level of difficulty in performing a task (Sauro, 2018); SUS (System Usability Scale), to evaluate the usability of the system with 10 questions (Brooke, 1995); and a customised GUI (Graphical User Interface) scale, which assesses different aspects of the graphical interface.

The participants answered the **Single Ease Question (SEQ) questionnaire** by rating each task after completing it. They rated on a Likert scale from 1 to 7 (very difficult to very easy). Table 31 shows that all tasks were, on average, evaluated above 6. Tasks 1, 7 and 8 were considered easier to perform, with all the participants rating them with the maximum value (7). On the other hand, tasks 4, 5 and 6 received the lowest evaluations. These three tasks are related to the definition of permeabilities. According to the mean, standard deviation and median values, the replacement of a door size (task 6) was considered the most difficult one.

Table 31_SEQ questionnaire applied during the formative evaluation with inhabitants: Results of each task

Tasks	Mean	SD	Mode	Median
Task 1- Selection of a room and its size	7	0	7	7
Task 2- Addition of a customised room	6,8	0,48	7	7
Task 3- Choose and customise a house layout	6,8	0,48	7	7
Task 4- Removal of a connection between rooms	6,2	1,10	7	7
Task 5- Removal of a wall	6,2	1,30	7	7
Task 6- Replacement of a door size	6,2	0,84	7	6
Task 7- Choose a kitchen layout	7	0	7	7
Task 8- Choose a flooring material for a room	7	0	7	7

After performing all tasks, the participants answered a **System Usability Scale (SUS)** questionnaire with ten questions to evaluate the system's usability. These predefined questions are alternately phrased positively and negatively. Each item is rated from 1 to 5 (totally disagree to totally agree). The SUS score is a number that represents the sum of each item's score, which ranges from 1 to 4 (Brooke, 1995). The odd items (1,3,5,7, and 9) scores are calculated by subtracting 1 from their scale position (X-1). On the other hand, for even items (2, 4, 6, and 8), the score is 5 minus the scale position (5-X). If, e.g. item 1 was classified as 4 on the Likert scale, its score contribution would be 3 (4-1=3), and if item 2 was classified as 1, its score contribution would be 4 (5-1=4). The total SUS score ranges from 0 to 100, and it is calculated by multiplying the sum of each item's contributions by 2,5. A score of 80.3 or higher is identified in the literature as an excellent rating (Brooke, 1995). Table 32 presents the results of the SUS questionnaire, showing the classification made by each participant to each SUS item. The total score of the SUS questionnaire was 91,5, which is excellent.

Table 32_SUS questionnaire applied during the formative evaluation with inhabitants: Results of each item and the total SUS score

	I1	I2	I3	I4	I5	Mean	Item score
Item 1- I think that I would like to use this system frequently	4	5	4	4	5	4,4	3,4
Item 2- I found the system unnecessarily complex	1	1	1	1	1	1	4
Item 3- I thought the system was easy to use	5	4	4	5	5	4,6	3,6
Item 4- I think that I would need the support of a technical person to be able to use this system	1	1	4	2	1	1,8	3,2
Item 5- I found the various functions in this system were well-integrated	4	5	4	5	5	4,6	3,6
Item 6- I thought there was too much inconsistency in this system	1	1	1	2	1	1,2	3,8
Item 7- I would imagine that most people would learn to use this system very quickly	5	4	5	5	5	4,8	3,8
Item 8- I found the system very cumbersome to use	1	1	1	1	1	1	4
Item 9- I felt very confident using the system	4	5	4	4	5	4,4	3,4
Item 10- I needed to learn a lot of things before I could get going with this system	1	2	1	1	1	1,2	3,8
Sum of item scores = 36,6							
SUS score (sum of item scores x 2,5) = 91,5							

Regarding the **Graphical User Interface (GUI)** questionnaire, nine statements, positively and negatively phrased, were asked alternately. The participants evaluated them on a scale of 1 to 5 (from "totally disagree" to "totally agree"). The results (Table 33) show that the negative statements obtained values with means up to 2.2, and the positive ones obtained mean values above 4.6, inclusive.

Table 33_GUI questionnaire applied during the formative evaluation with inhabitants: Results of each statement

	Mean	SD	Mode	Median
1- I understood the names of the project phases	5	0	5	5
2- It is not easy to navigate through the menus	1	0	1	1
3- I understood the menu options and indications	4,6	0,55	5	5
4- The menu icons and buttons do not clearly indicate their function	2,2	1,30	1	2
5- The diagrams are easy to read and understand	5	0	5	5
6- The graphic design of the screens is not well-designed	2,2	1,64	1	1
7- The information is well organised on the screens	4,8	0,45	5	5
8- It's not easy to access the information I need	1,2	0,45	1	1
9- The buttons and text sizes are appropriate	4,8	0,45	5	5

Since these questionnaires depend on the subjective perception of respondents, the data gathering was complemented with **observations of the participants' task performance**. Each task consisted of a set of steps that should be performed to complete it. The success or failure in carrying them out was registered, as well as the number of attempts made, and the time it took participants to complete them successfully. The success of completing each step was considered if the participant achieved it within three attempts. If not, the researcher intervened, explaining what was supposed to be done, registering it as not completed, and asking the participant to proceed with the next step. Although the time to complete each task was measured to compare with the difficulty in achieving them, this measure is not relevant by itself, since the feedback time of the system is not accurately simulated in tests performed with low-fidelity prototypes (Gonçalves, Fonseca and Campos, 2017).

According to the results (Table 34), all the participants completed all the steps of tasks 1, 2, 3, 7, and 8. Tasks 4 and 6 were completed by four individuals, and task 5 was completed by three individuals. None of the tasks had all steps completed by every participant in the first attempt. However, task 2 was completed by four participants, with all steps completed in the first attempt. On the other hand, tasks 3, 4, 5 and 6 had all the steps completed in the first attempt by only one participant. Task 3 was the longest, being completed in an average of three minutes and seven seconds (187 seconds), and task 6 was the quickest, with an average of 52,5 seconds.

Table 34_Results of the observation of task performance by inhabitants in the formative evaluation

	Completed all the steps of the task (Number of participants)	Completed all the steps of the task in the first attempt (Number of participants)	Time average to complete the task (seconds)	Standard deviation
Task 1	5	2	67	21,9
Task 2	5	4	79,4	49,2
Task 3	5	1	187	52,8
Task 4	4	1	114	33,9
Task 5	3	1	179,2	36,5
Task 6	4	1	52,5	34,9
Task 7	5	3	105	45,8
Task 8	5	2	80,8	25,1

Participants were also asked to list what they felt were the **best and worst aspects** of the experience. The results are summarised in Figure 107. According to the inhabitants, the system has the following **strong points**: i) several options to choose from; ii) double visualisation modes (plan view and 3D); iii) direct interaction with the house design; iv) seeing results in real-time; and v) ease of use.

On the other hand, the **negative aspects** identified by participants refer to: (i) the system's feedback mechanisms; (ii) the definition of permeabilities; (iii) the customisation of specific aspects of the house; (iv) the customisation of the interface; and (v) the absence of a catalogue of predefined house layouts.

The system's feedback (i) refers to the information that should be conveyed to users via the interface, such as highlighting selectable elements. It also includes providing details about rooms when selected (e.g., room dimensions or areas) and notifying users when they attempt to drag elements to inappropriate areas of the interface (an interaction that could not be replicated in the paper prototype).

Issues concerning the definition of permeabilities (ii), i.e., the connections between rooms, were primarily associated with the lack of visibility of options for removing connections, or a clear way to do it. Some participants said they encountered difficulties in completing this task, as it required selecting the connection to reveal a pop-up menu with the removal option. Similarly, when removing a wall, users first had to select the "total" option from the library before selecting a wall to remove. Consequently, participants expressed that the process for removing connections should be revised, as it was perceived as confusing.

Further suggestions for improvement were related to the customisation of various aspects of the house (iii). Participants proposed the possibility to customise the application area of materials, e.g. allowing the use of more than one material per room, adjust room sizes either by specifying dimensions or by directly manipulating walls within the design, and expanding the system libraries to include options that users can customise on the spot in addition to the predefined ones.

Participants also recommended improvements to the interface itself (iv). These included the ability to resize workspaces, reposition the button for adding customised rooms (suggesting it be placed at the top of the list), and revise the labels of the phase navigation buttons. Specifically, they suggested replacing the phase names with more intuitive labels such as “Next” or “Previous”, since the phases were already tracked at the top part of the interface.

Finally, the proposed catalogue of predefined house layouts (v) was intended to offer users a selection of complete housing layout templates that could be further customised, rather than requiring them to begin by specifying individual room requirements.

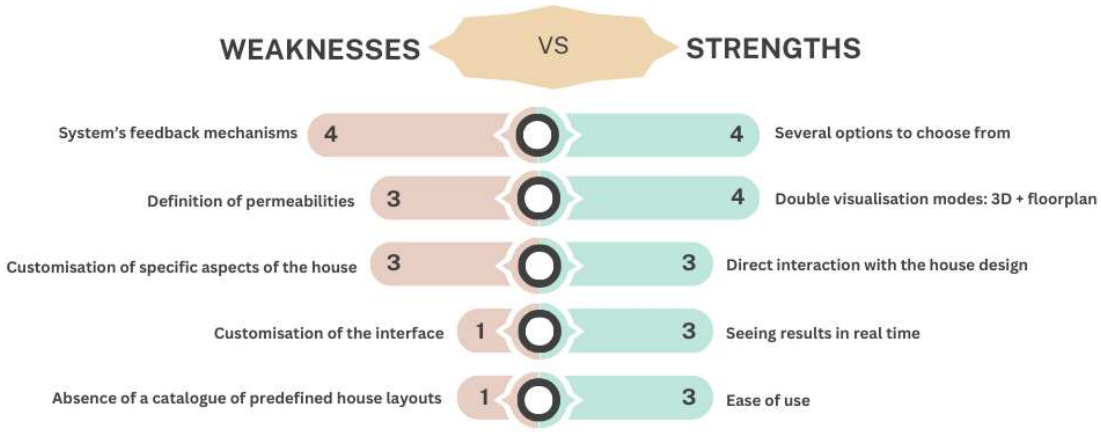


Figure 107_Overview of the weaknesses and strengths identified by the inhabitants during formative evaluation

The observations also allowed to identify opportunities for improvement. According to what the inhabitants reported, it was observed more difficulty for participants in performing the tasks related to the permeabilities than in other phases of the process. It was also observed that dragging icons from the library was not intuitive, as the participants tended to click on options instead of dragging them.

5.1.1 Discussion

The formative evaluation with inhabitants aimed to determine whether the proposed interface meets potential users’ needs and identify opportunities for improvement. A low-fidelity paper prototype was used. As it was the first evaluation of the interface, the aim was to identify workflow issues rather than visual and aesthetic details of the design. Similarly, some interactions or system feedback could not be simulated at this phase.

The results show that the proposed interface is accessible to its target, although some improvements can be made. The resulting score of the SUS questionnaire shows that usability is excellent, according to the literature (Brooke, 1995). The results of the SEQ questionnaire, which evaluates the ease of task execution, indicate that the interface is user-friendly. Even the lower-rated tasks achieved a mean of 6.2 on a 7-point scale, suggesting a high overall ease. The GUI questionnaire results also further indicate user satisfaction with the interface, since the positively phrased statements were rated with a mean value above 4.6 and the negatively phrased statements had means up to 2.2, underscoring a strong positive perception of the interface. These values show that the results are close to the best evaluation scenario (the most favourable outcome would be a mean of 5 for the positive statements and 1 for the negative ones).

Although the general positive results, the **SEQ questionnaire** served to identify specific parts of the interface that need improvement. Tasks related to the definition of permeabilities (Tasks 4, 5, and 6 – removing a connection between rooms; removing a wall; and replacing a door size, respectively) were perceived by participants as the most challenging. The observations confirm this perception, revealing that these tasks were the only ones for which some participants were unable to complete all their steps within three attempts. Notably, each of these tasks was successfully completed on the first attempt by only a single individual, further highlighting their relative complexity.

Task 6, which involved replacing the size of a door, was perceived as the most difficult to perform. Although its mean rating was equivalent to that of Tasks 4 and 5, the results for Task 6 demonstrated greater consistency in lower values, as evidenced by standard deviation and median values. This outcome was unexpected, given the relative simplicity of the task, which comprised only two steps: (1) selecting the door on the floorplan, and (2) dragging a size option from the library into the floorplan. The drag-and-drop interaction was presumed to be intuitive, particularly as it had been employed in earlier phases, such as when dragging room sizes during the definition of household requirements.

A possible explanation for this result may lie in the difference in interaction patterns. In Tasks 4 and 5, users were required to click on elements within the floorplan to reveal pop-up menus. It is possible that participants expected Task 6 to follow the same interaction model, leading to confusion when it did not. Another factor that might influence the perceived difficulty or complexity of a task is the number of steps required for completion. However, this hypothesis is not fully supported by the observational data. For instance, Task 1, which involved three steps — (1) selecting the space (e.g., bedroom), (2) specifying the number of occupants, and (3) dragging the room size — was among those most easily completed by participants.

No clear relationship was identified between **task completion time and the rate of task completeness** (measures of efficacy and effectiveness). For instance, Task 2 demonstrated the highest effectiveness (full completion by all participants, with a greater proportion completing all steps on

their first attempt). Nevertheless, Task 2 required more time to complete than Task 6, which was completed on the first attempt by only one participant. A possible explanation for this finding is that easier tasks may nonetheless require more time if they involve a greater number of procedural steps.

One of the lowest-rated items in the **GUI questionnaire** was Statement 4: "The menu icons and buttons do not clearly indicate their function". Although the GUI questionnaire addresses general aspects of the interface, it can be argued (based on both perceived and observed data concerning task difficulty) that this evaluation primarily concerns the permeabilities phase. For example, the “total” option in the library, intended to remove an entire wall, may have contributed to user confusion about its function, due to its unclear labelling.

Regarding **strengths and weaknesses**, the most frequently cited weak aspect was the system’s feedback mechanisms. As previously noted, certain interactive features cannot be effectively simulated using a paper prototype. Nonetheless, the suggestions provided by the inhabitants were considered in the development of the high-fidelity prototype. These included developments such as visually highlighting selectable items and providing contextual information. The need for improvements is also related to the task of defining permeabilities, which was revealed to be confusing for the participants due to hidden menus and an unintuitive order of actions.

5.2 Interface refinement

This subchapter provides a detailed description of the interface refinement. A high-fidelity functional prototype was created using Figma (Figma Inc, 2016), a codeless online tool for interface design. This prototype accommodated the changes considered necessary after analysing the results of the tests performed with the paper prototype during the formative evaluation, and from additional developments considered relevant to the progression of the work. The latter include the design of the initial part of the interface, from the login and choosing the apartment process through to the point at which the inhabitant begins the first phase of defining the interior of a house, namely the specification of household requirements.

5.2.1 Changes derived from the formative evaluation

During the formative evaluation, it was observed that, despite being identified as a preferred option in the interviews, the drag-and-drop interaction was not perceived as natural in practice. Participants tended to click on the library options rather than dragging them to the working area, even when indicated by instructional sentences. Consequently, the interaction method was modified: selecting an option, by clicking on it, automatically inserts it into the design. The drag-and-drop interaction was maintained in contexts where it aligns more naturally with the task, such as direct space manipulation,

e.g., repositioning rooms within the housing layout, or assigning finishing materials to specific areas of the house.

Another significant change was in the permeabilities task, since during the formative evaluation, it became evident that the processes of modifying and removing spatial connections were not intuitive for potential users. Firstly, it was determined that the option to eliminate doors was conceptually inappropriate, as rooms inherently require passageways. Consequently, this option was removed, and only the functionalities for resizing openings and repositioning doors were maintained. The needed elements, such as the library of size options, are visible, eliminating the need for pop-up menus.

Walls can still be removed to enable the creation of, e.g., open-plan spaces, if such modifications do not compromise structural integrity or interfere with infrastructure. However, the "total" option was eliminated from the library, and the removal of walls was decoupled from the connections' predefined size options.

The permeabilities task is now divided into two distinct features: one for modifying door openings and another for removing walls, each activated via separate buttons. To modify door openings (Figure 108), users may reposition them by dragging directly on the floorplan or change their dimensions by selecting the opening and clicking a new size from the library, which is then automatically updated in the floorplan. To remove walls (Figure 109), users activate the wall editing button and then click directly on the wall to delete it.

In the door editing mode, walls are visually faded to emphasise the door elements. In contrast, when the wall removal function is active, doors appear faded to shift focus to the walls. Interactive elements, such as doors and eligible walls, are highlighted while hovering the cursor.

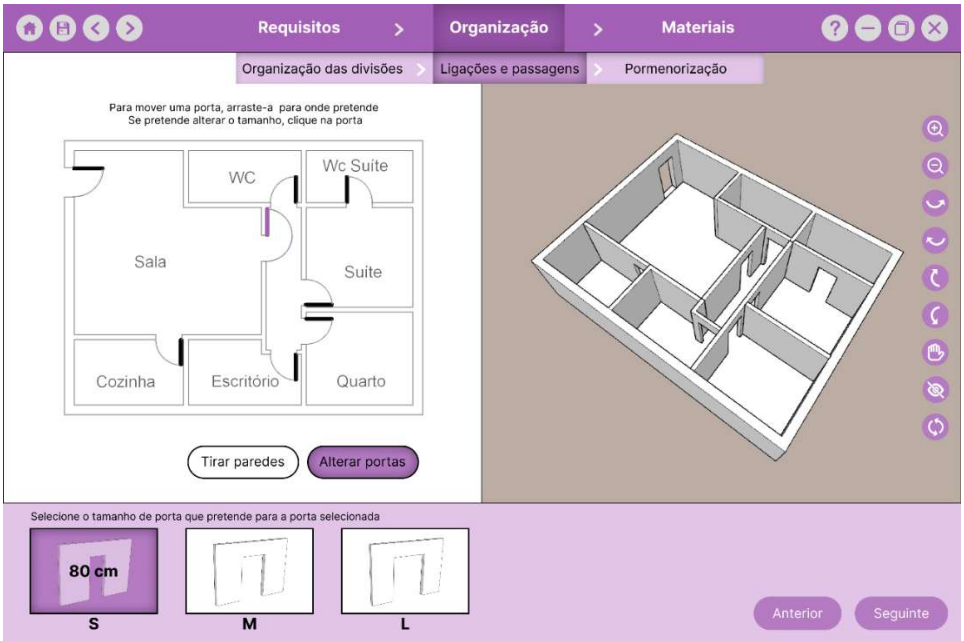


Figure 108_High-fidelity digital prototype interface with the changes made to the permeabilities task. "Editing doors" button activated, and a repositioned door with S size selected

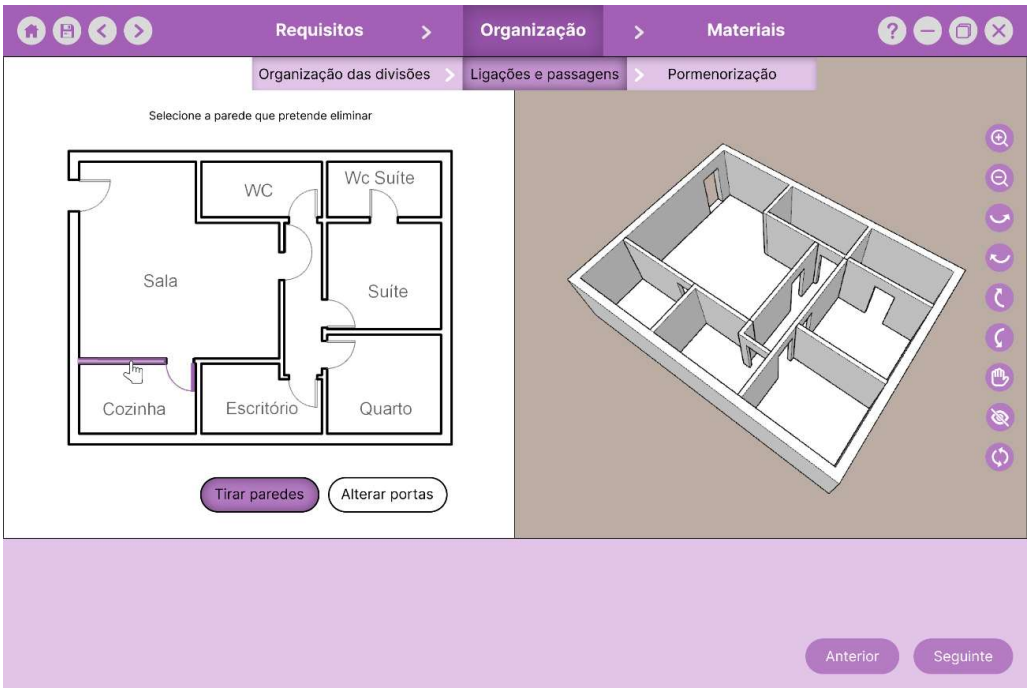


Figure 109_High-fidelity digital prototype interface with the changes made to the permeabilities task. "Remove walls" button activated, and the wall selected to be removed.

Other, less structural modifications were made to the interface. The labels of the phase navigation buttons were replaced by "Next" (*Seguinte*) or "Previous" (*Anterior*). Also, some supporting information was added, such as labelling the library options (e.g., room areas in the Definition of household requirements phase, as depicted in Figure 110), and highlighting selectable items in the floor plan (e.g., kitchens and bathrooms in the Detailing phase (Figure 111), when hovering the cursor.

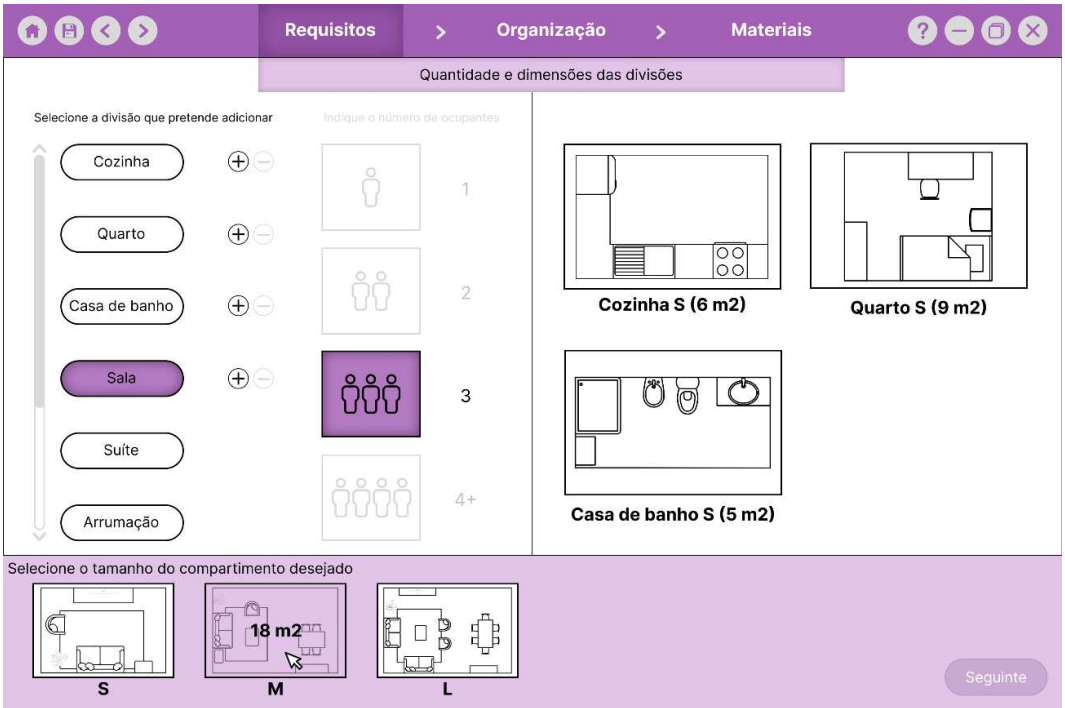


Figure 110_High-fidelity digital prototype interface within the Definition of household requirements phase, with the room area labelled while hovering the cursor over the M library option

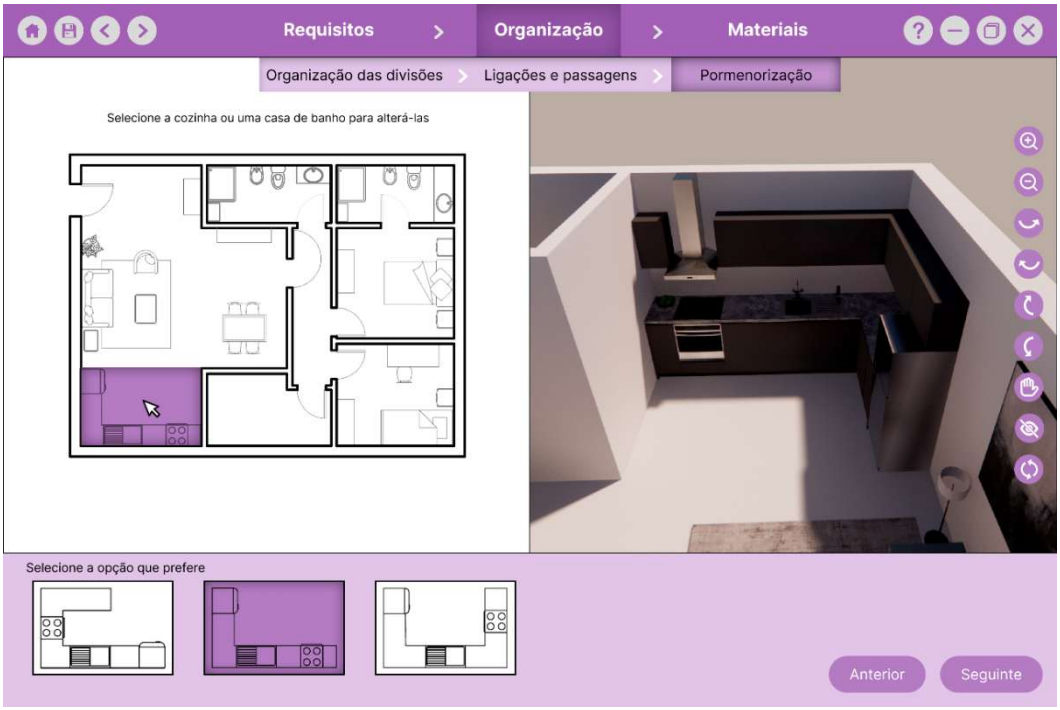


Figure 111_High-fidelity digital prototype interface within the Detailing phase, with the kitchen highlighted in the floor plan and a kitchen layout selected

Also at the Detailing phase, the 3D visualisation was rendered dynamically, automatically orienting the viewpoint toward the selected room for a clear visualisation of the design decisions. To improve spatial perception, users may opt to temporarily hide walls by selecting the corresponding function in the sidebar menu located on the right side of the screen, where the 3D model is displayed. Upon activation, users can then select individual walls to hide (Figure 112). To unhide, users reselect the menu option, which returns all previously hidden walls.

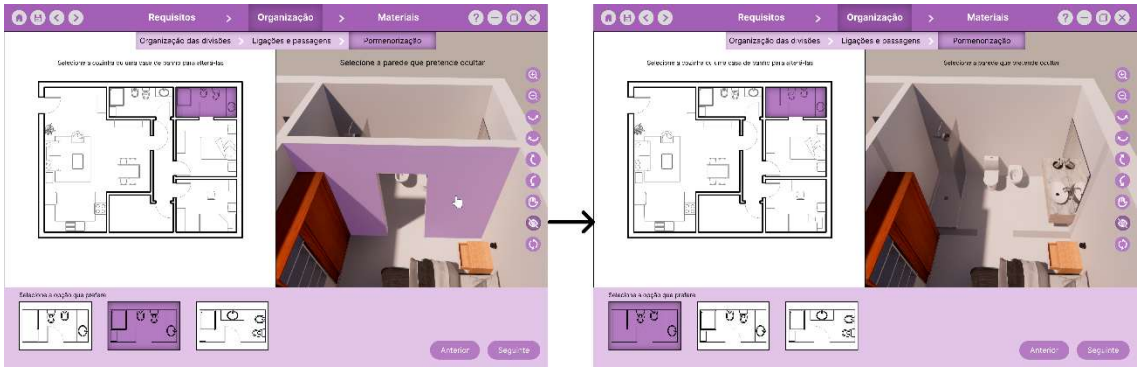


Figure 112_High-fidelity digital prototype interface within the Detailing phase, with the 3D viewpoint oriented to the selected bathroom. Left: "Hide" button activated and a wall being selected. Right: Selected wall hidden, and other bathroom layout selected in the library and reflected in the design.

5.2.2 Further developments considered relevant

Besides the improvements made based on the formative evaluation results, additional developments in the high-fidelity prototype include the design of the initial part of the interface. A login/sign-up interface was designed, as well as a "Home" menu for the user to access the project (Figure 113). After choosing the project, the user accesses the building's menu (Figure 114) where the following options are available (from right to left, top to bottom): "Location" (*Localização*), for seeing the location plan of the building and its surroundings; "Images of the building" (*Imagens do edifício*), to see rendered images of the entire building from an outside perspective; "Customise dwellings" (*Personalizar habitações*), to proceed to the interior dwelling layout customisation; "Common areas" (*Áreas comuns*), where the user can see the floorplan of the building with the common areas instead of their apartment's detached floorplan; "Building Specification" (*Ficha técnica*), to access the building specification sheet, including construction area and other technical data; and "Energy efficiency" (*Eficiência energética*) for consulting the performance of the building. Although these options were defined, only the "Customise dwellings" option was further detailed since it was the focus of the research.



Figure 113_Additional developments in the high-fidelity prototype: interface developed for the Home menu

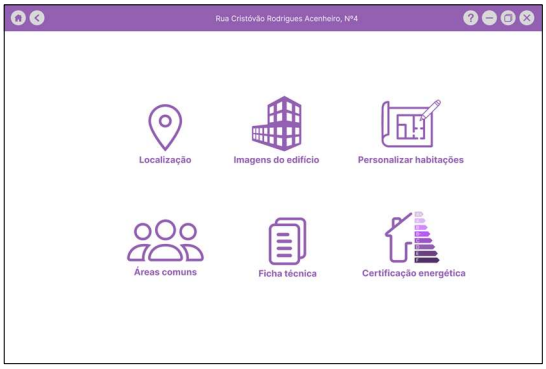


Figure 114_Additional developments in the high-fidelity prototype: interface developed for the Building menu

By clicking on the "Customise dwellings" option, the user accesses an interface where the building floorplan is shown (Figure 115). The interactive floorplan allows users to select the apartment they want, while being assisted by a pulsing sentence ("Select the house you want" – "*Selecione a habitação que pretende")* that gives the instructions on what to do. This sentence is similar to the ones presented in all the subsequent phases of the housing definition process. The building floor can be changed through the back and forward arrows placed on the sides of the floorplan. When an apartment selection is confirmed, the user accesses the first phase of the housing layout customisation: the definition of the household requirements.

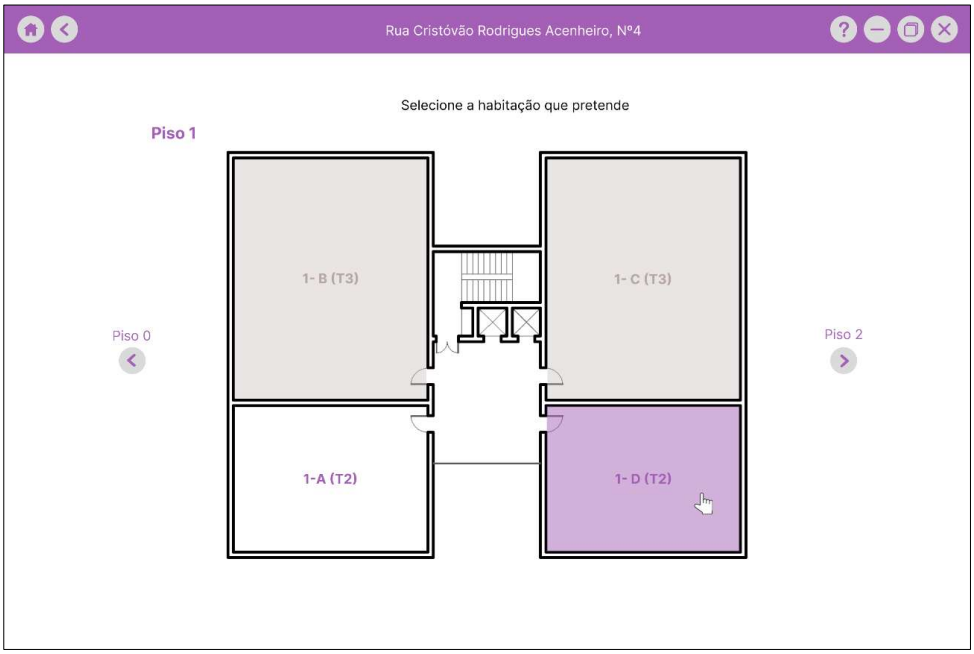


Figure 115_Additional developments in the high-fidelity prototype: interface developed for the choice of the apartment in the building floorplan

The material selection process was also further developed (Figure 116). A pop-up window was introduced to present multiple options for each material type. Each option is accompanied by representative images illustrating its visual characteristics and typical applications. Additionally, supplier information and associated costs are displayed upon cursor hover, facilitating informed decision-making. Once a specific finishing material is selected, it is represented in the library, from where the user can drag it to the part of the house they want to assign this material.

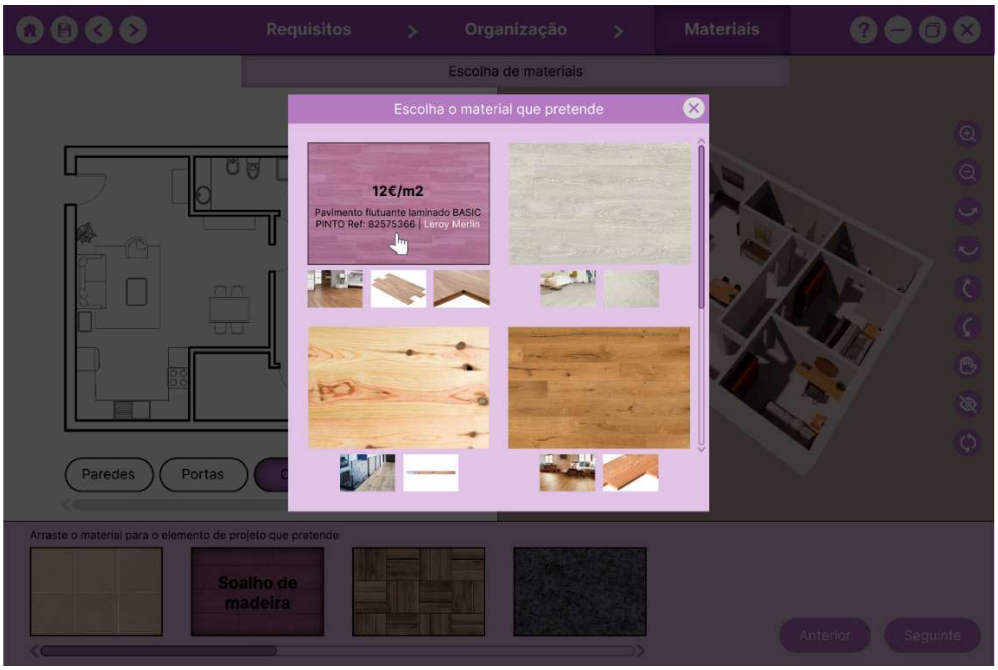


Figure 116_Additional developments in the high-fidelity prototype: material selection through a pop-up window with different options for a wooden floor. The option highlighted shows the information about the supplier's product and associated costs

An interface was also developed to provide an overview of user decisions concerning room areas and selected finishing materials. This interface presents the automatic calculation of the materials budget based on the specified application areas (Figure 117). At this stage, users may finalise their design customisation by clicking the "Submit" ("*Submeter*") button located in the bottom-right corner of the interface. Upon submission, the customised housing layout is integrated into the building's general floorplan (Figure 118).



Figure 117_Additional developments in the high-fidelity prototype: Overview interface with the chosen areas and finishing materials, and their budget

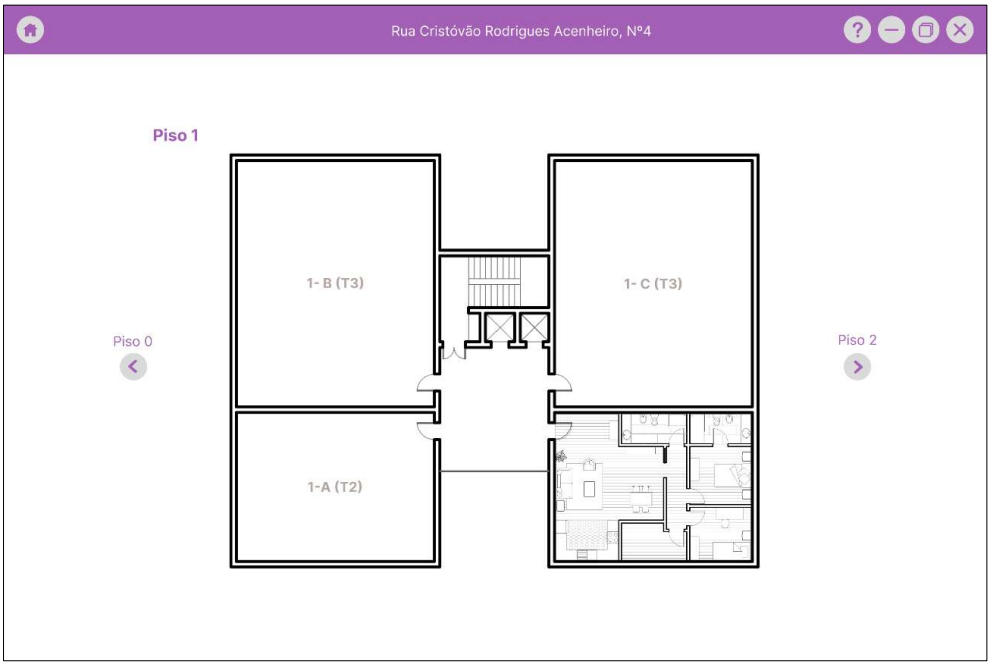


Figure 118_Additional developments in the high-fidelity prototype: customised housing layout is integrated into the building's general floorplan

5.3 Interface evaluation using a High-Fidelity prototype

The high-fidelity prototype was tested with **experts** in user interface (UI) and user experience (UX), **inhabitants** (potential users) and **architects**. The initial evaluation with experts was intended to inform a new refinement of the interface to enhance its usability. The refined version was tested with inhabitants (Figure 119) to assess its practical usability in real-world scenarios. The interface was also used by a group of architects (Figure 120) to gather their perception regarding the use of such a tool for a co-design process. The study was conducted in an indoor environment with controlled noise and lighting to ensure participant focus. The equipment used was a Surface Pro 8 with a keyboard and a mouse connected.



Figure 119_Summative evaluation with potential users



Figure 120_Discussion with architects

The study was conducted with five interface experts, thirty inhabitants and ten architects. Interface Design experts and architects were selected for their professional practice, with age or gender not being considered in the choice of participants. In the case of the inhabitants, the participants were selected to keep the following characteristics in balance: age, gender, and education level (compulsory or higher education).

All the participants were initially recruited through convenience sampling within the researcher's personal network and subsequently expanded using snowball sampling. The contacts were made between April 26th 2023 and May 31st 2023, and the only mandatory requirement was that the inhabitants should be between 25 and 45 years old (age range identified as potential users of the tool during the interviews). All the participants agreed to participate in the study according to the user study protocol approved by Iscte—Instituto Universitário de Lisboa Ethics Committee. They agreed to participate in the experience and signed a written consent form. Similar to the tests conducted with the paper prototype, participants performed predefined tasks to interact with the system in different phases, exploring the various features.

The evaluation with interface experts, the goal was to identify usability problems that users could face and to correct them before carrying out the final tests with inhabitants and the discussion with

architects. These problems were identified and categorised according to their frequency and degree of severity to define an order of priority in their resolution.

The tests with inhabitants were intended to evaluate the system's usability and user-friendliness. Therefore, after experiencing the features, they answered three questionnaires (SEQ - Single Ease Question, SUS - System Usability Scale, and GUI - Graphical User Interface). They were also asked to identify three best and three worst aspects of the system. the success or failure of completing the tasks and the time it took to complete them were also registered.

Regarding architects, the aim was to collect their perception, as experts in design, about the benefits and limitations of using this design tool by inhabitants and in the scope of a co-design process and definition of customised housing. The following sections describe the results of tests with each of the three groups mentioned above.

5.3.1 Heuristic evaluation with interface design experts

A heuristic evaluation was conducted with the five interface design experts to comply with the recommendations identified in the literature, which recommends the involvement of at least 3 to 5 experts (Nielsen, 1994d). The selected participants are recognised as experts in user experience (UX) and User interface (UI), with publications in the field. They identified usability issues and rated them with severity levels according to Nielsen's scale (Nielsen, 1994c) from 0 to 4: 0) I don't agree that this is a usability problem at all; 1) Cosmetic problem only: need not be fixed unless extra time is available on the project; 2) Minor usability problem: fixing this should be given low priority; 3) Major usability problem: important to fix, so should be given high priority; and 4) Usability catastrophe: imperative to fix this before the product can be released. The experts identified a problem, pointed it out in the interface, described it, rated it, and proposed a solution. Figure 121 shows an overview of all the usability issues identified. A detailed description of each usability issue resulting from the heuristic evaluation made by the UX/UI experts is given in Appendix C.

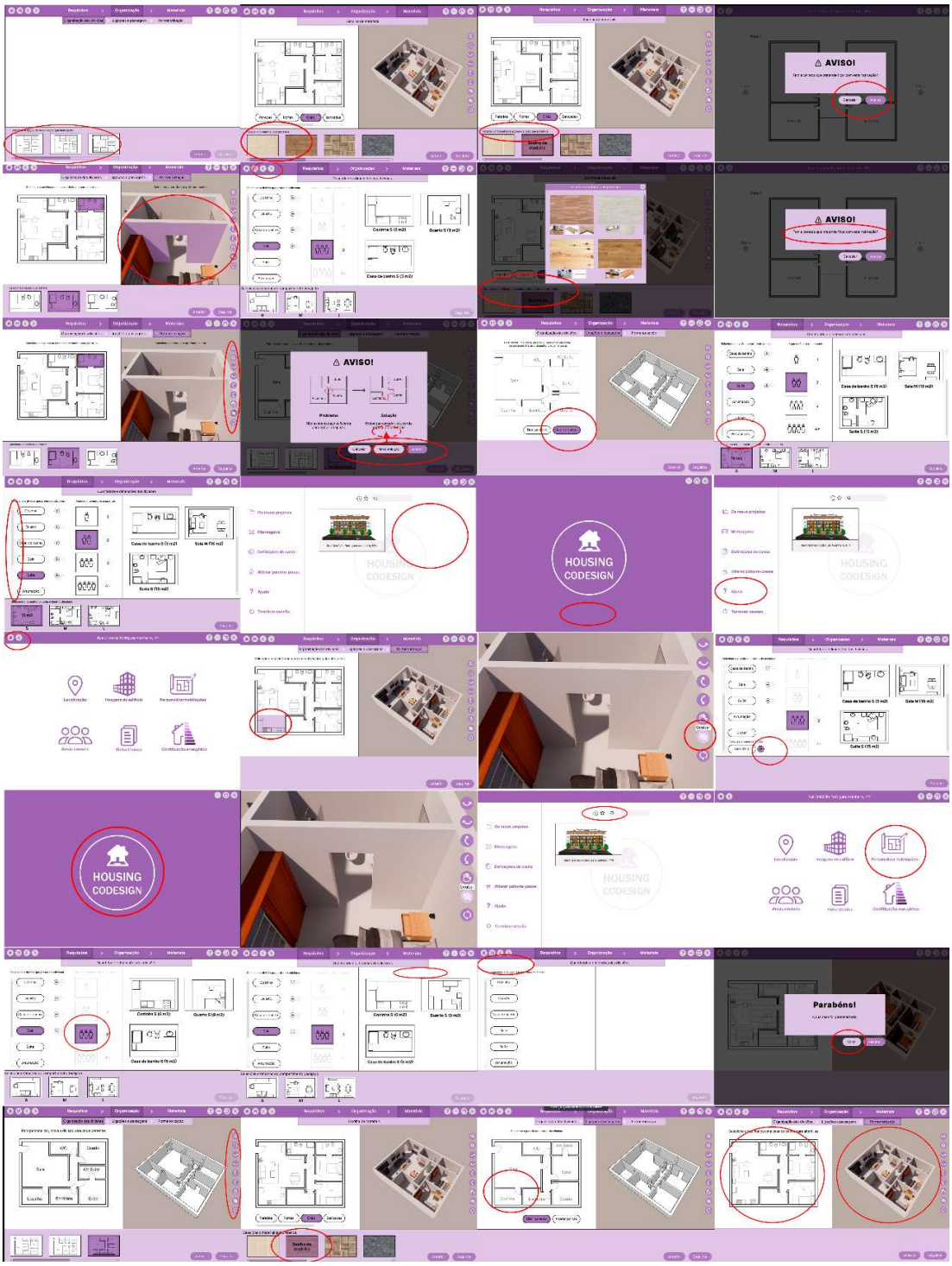


Figure 121_Overview of all the usability issues identified by the experts, showing the interface and the location of the issue

A consolidation of the heuristic evaluation results is presented in Table 35. The issues are ordered by priority. The "Expert severity rankings" refer to the level of severity each expert attributed to the issue. The violated heuristic refers to the Nielsen's heuristic (Nielsen, 1994a) which the issue violates. The consolidated severity is determined according to the highest severity attributed to the issue when more than one expert identified it, and the frequency refers to the number of experts who identified the issue.

Table 35_List of usability issues identified by the experts, ordered by priority

Issue	Expert severity rankings*					Violated heuristic	Consolidated severity*	Frequency**	Priority***
	E1	E2	E3	E4	E5				
Library options' caption		3	2	3		H6	3	3	P1
Order of associating the material with the element	3			2		H5, H7 and H8	3	2	P1
Drag the material			2		3	H1	3	2	P1
Warnings	3	3				H5	3	2	P1
Order of hiding walls in the 3D view	3			2		H7	3	2	P1
Undo/Redo	3					H4	3	1	P2
Applying the material		3				H5 and H8	3	1	P2
Irreversible action information	3					H5	3	1	P2
3D model menu option	3					H1	3	1	P2
Accept/cancel new solution	3					H2	3	1	P2
Order of changing the doors			3			H7	3	1	P2
"Customise" button	3					H4	3	1	P2
Scroll		3				H1	3	1	P2
"My projects"	1			2		H3	2	2	P3
Start	2					H1	2	1	P4
Help	2					H4	2	1	P4
Home and Back buttons	2					H4	2	1	P4
Identification of rooms on the floorplan	2					H6	2	1	P4
"Hide" button denomination					2	H1	2	1	P4
Cancel button on the customise room option	2					H3	2	1	P4
Logo		2				H2	2	1	P4
"Hide" icon		2				H2	2	1	P4
Icons in "my projects" interface	1					H8	1	1	P5
"My home"	1					H2	1	1	P5
Number of occupants	1					H1	1	1	P5
"Choices made" identification	1					H1	1	1	P5
Apartment identification	1					H6	1	1	P5
"Continue customising" button	1					H2	1	1	P5
3D orthographic views	1					H7	1	1	P5
Materials denomination		1				H2	1	1	P5
Delete walls			1			H2	1	1	P5
Windows				1		H2	1	1	P5

Caption:
*__Severity__: **3** = major usability issue, **2** = minor usability issue, **1** = cosmetic problem only.
Heuristics: H1= Visibility of system status; **H2**= Match between the system and the real world; **H3**= User control and freedom; **H4**= Consistency and standards; **H5**= Error prevention; **H6**= Recognition rather than recall; **H7**= Flexibility and efficiency of use; **H8**= Aesthetic and minimalist design; **H9**= Help users recognize, diagnose and recover from errors; **H10**= Help and documentation.
__Frequency__: **3 = identified by three experts; **2** = identified by two experts; **1** = identified by one expert.
***__Priority__: **P1** = more frequent and severe; **P2** = severe non-frequent; **P3** = frequent non-severe; **P4** = non-severe nor frequent; **P5** = Just aesthetic problem.

The experts identified 32 usability issues. Based on the severity assessment, the consolidated results show that ten issues are classified as Severity Level 1 (cosmetic problems only), nine as Severity Level 2 (minor usability problems), and thirteen as Severity Level 3 (major usability problems). Six issues were reported by more than one expert: five belonged to Severity Level 3 and one to Severity Level 2.

The most frequently violated heuristics were H2 (Match between the system and the real world), cited in eight instances, and H1 (Visibility of system status), cited in seven. Additional infringements were observed across heuristics H3 through H8. Specifically, H4 (Consistency and standards), H5 (Error

prevention), and H7 (Flexibility and efficiency of use) were each violated in four cases; H6 (Recognition rather than recall) and H8 (Aesthetic and minimalist design) in three cases; and H3 (User control and freedom) in two cases.

Based on the results, five priority levels were established to guide the resolution of usability issues. These levels were determined by combining the severity rating (Levels 1, 2, or 3) with the frequency of expert identification (i.e., whether the issue was identified by one, two, or three experts). As illustrated in Table 35, the highest priority (P1) is assigned to issues that are both severe and frequently reported. This is followed by P2 (severe but infrequent), P3 (frequent but non-severe), P4 (neither severe nor frequent), and P5 (cosmetic issues that do not require resolution).

Priority levels P1 and P2 correspond to Severity Level 3 issues, P3 and P4 to Severity Level 2, and P5 to Severity Level 1. A detailed description of the most critical and frequently reported issues (P1) is provided below.

Library options' caption. The library options are not identified by a caption, which makes it difficult for the user to identify them. Users should not have to memorise them.

Order of associating the material with the element. Since the task is to choose a material, when the material is selected, the user considers the task complete, forgetting to associate it with a room. Thus, the steps must be done in reverse order.

Drag the material. The instruction for the user to drag the material to the desired room/ element, despite pulsing, does not stand out (when solving the previous issue, it is no longer necessary to drag the material, and therefore the pulsing sentence can be deleted).

Warnings. When warnings about important actions appear, the highlighted button should be the "cancel" button to prevent the user from doing actions they do not intend to by clicking the button without paying attention to its function.

Order of hiding walls in the 3D view. The walls can be hidden in the 3D menu to better visualise the rooms. However, the system should allow selecting a wall and then giving the instruction to hide it and vice versa, because different users can act differently.

Additional usability issues include the order of changing permeabilities, the need to change buttons or icons, indicating that certain actions are irreversible among others. As previously noted, the description of each usability issue is provided in Appendix C. The next section describes the changes made to the interface in the second interface refinement.

5.3.2 Second interface refinement

A new interface refinement was made based on the priority list, which resulted from the consolidation of the issues identified by the experts. The issues were solved by order of priority, and their resolution followed the experts' suggestions during the heuristic evaluation. A demonstration video using the ultimate version of the refined high-fidelity prototype is available at https://www.youtube.com/watch?v=ICupzsr9MlQ.

Only seven of the 32 issues identified were not solved. Almost all were from the lowest priority levels (P4 and P5). Four issues were categorised as cosmetic issues that do not need to be solved (severity level 1), and for this reason, they were not solved. Such issues are: "3D orthographic views", "Materials denomination", "Delete walls", and "windows".

Two issues ("Logo" and "Hide icon") were categorised as minor usability issues (severity level 2). They were not solved because it was considered that these issues do not interfere with the interface's usability, as other features guarantee usability. The Hide icon was identified as an icon that does not immediately refer to its purpose, however, while hovering the cursor, the denomination of the button appears, so the users know the button's purpose even if they do not recognise the icon. The logo in English was considered by experts to be withdrawn for Portuguese participants, as they may think that the entire interface will be in English, however, it was also considered that the usability is not compromised by this issue, since the features of the entire interface are in Portuguese. Also, the interface is envisioned to be adapted to other geographical contexts, and therefore, an English logo is adequate for a broader international context.

The "Scroll" issue, identified as severe but non-frequent (P2), was also not solved. It consists of hidden features that are accessible through a scroll bar. Scrolling should be avoided as all the necessary information should be visible on the screen, even if it implies dividing the features across more screens. This issue was not solved because, although classified as severe (level 3), it was only identified by one expert. The resolution of such an issue would imply a significant intervention in the interface, which would significantly impact the research progress.

The changes made to the interface included the suggestions of the experts, and some changes solved more than one issue. Regarding the P1 issues, **the library options were labelled** so that the users do not need to memorise them when exploring the options using the horizontal scrollbar. This included labelling housing layout options in the "Organisation" ("*Oganização*") task as "1, 2, 3, (…)" (Figure 122), and labelling the kitchen and bathroom layout options in the "Detailing" ("*Pormenorização*") task (Figure 123). Bathrooms are labelled as "1, 2, 3, (…)", and kitchen options are labelled by their layout type (e.g., "U-shaped", "L-Shaped", "Peninsula", etc). Other labels (such as S, M, L) and additional dimensional information upon hovering were already implemented in the other phases, such as the rooms and door sizes.

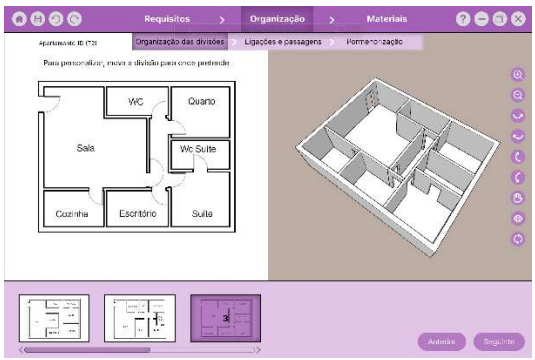


Figure 122_Refinement of the High-fidelity prototype: library options labelled in the "Room organisation" task. The third option is selected and labelled as "3"



Figure 123_Refinement of the High-fidelity prototype: library options labelled in the "Detailing" task while detailing a kitchen layout. The second option is selected and labelled as "L-shaped". The kitchen is also highlighted in the floorplan and identified as "kitchen"

The finishing materials assignment was modified by adding the feature to first click the room where the material is intended to be assigned, and then choose the material wanted. This refinement addresses three interrelated usability issues: "order of associating the material", "drag the material" and "applying the material". These issues are related to users' tendency to neglect assigning a material to a room, primarily because the goal is to choose the material. Additionally, the instruction sentence to drag the selected material lacked visual distinction, and the practice of dragging items from an element that gives access to a menu containing multiple options is not advisable, specifically because users may be uncertain about which option is being dragged. Additionally, an interface element should not support dual interactions (open a pop-up menu and being dragged from the library to the design). The revised interaction model solves these concerns by requiring users to first select the room before choosing the material. This sequence ensures that users do not forget to assign the material after selection. Moreover, the new approach eliminates the need for dragging items from a primary menu.

The order of hiding walls in the 3D view was considered to accommodate an alternative. Although it was not possible to simulate in Figma, it is proposed that the user can first select the wall and then press the "Hide" option on the 3D menu. The order of modifying doors was also improved, allowing users to directly reposition doors without activating the button "modify doors". In such a case, the button is automatically activated. Such improvements complement the interactions previously implemented, complying with Nielsen's heuristic 7 (Flexibility and efficiency of use). In the "Detailing" phase, a further development was the automatic hiding of walls when a kitchen or bathroom is selected and the viewpoint is redirected to the room. This modification is considered appropriate, since the best viewpoint of the room must be displayed.

The interface was refined to prevent errors. Regarding warnings (e.g., Figure 124), the button "Cancel" was highlighted instead of the "Accept" button. Also, confirmation warnings with irreversible action information, such as, e.g. when choosing the apartment to start customising, were added.

Regarding the system feedback concerning the spatial redistribution process within the "rooms organisation" task (Figure 124), the button previously labelled “New Solution” was renamed to “Generate Alternative” and repositioned below the proposed solution. This modification aimed to enhance clarity. In its earlier placement, the button was grouped alongside “Cancel” and “Accept,” which led to ambiguity regarding its specific function. The “Cancel” and “Accept” buttons were also given a label while hovering.

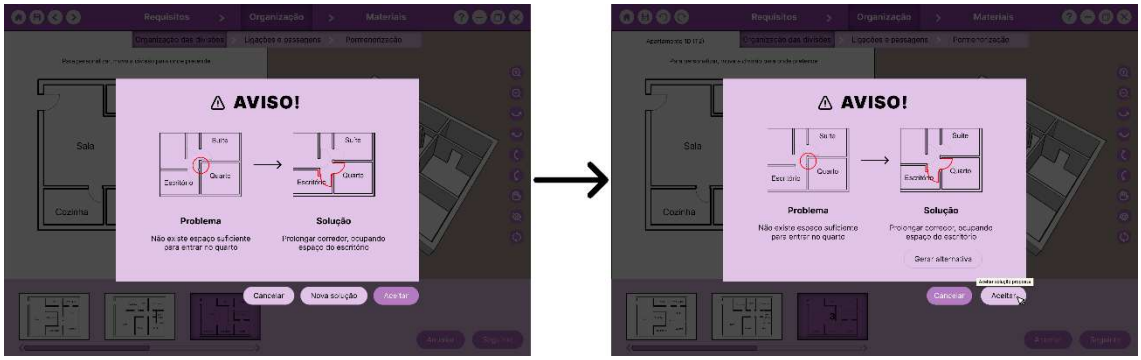


Figure 124_Refinement of the High-fidelity prototype: Warning concerning the spatial redistribution within the “Rooms organisation” task. Left: Previous version with the button “accept” highlighted and the button “New solution” grouped with the “Accept” and “Cancel” buttons. Right: refinement, with the “Cancel” button highlighted and the button “New solution” relabelled as “Generate alternative” and repositioned below the proposed solution. The cursor is over the “accept” button, and a label is shown.

To enhance visual feedback, the **3D menu buttons were modified to display a contrasting colour** (white) when selected. This adjustment was made in response to the previously used darker colour, which failed to provide sufficient visual distinction and did not effectively communicate the selected status to users.

The remaining low-priority usability issues were addressed to refine the overall interface and user experience. These improvements included **modifications to specific labels and icons, as well as the integration of contextual information** (Figure 125). For instance, an explanatory note was added to clarify why the number of occupants is restricted in common areas (this constraint derives from the predefined household configuration). Further enhancements involved the inclusion of apartment identification and the addition of a descriptive title in the section of the interface that refers to the choices made. Additionally, room identification within the floorplan during the “Detailing” and “Choice of materials” tasks, when a room is selected, was added (see e.g. Figure 123).

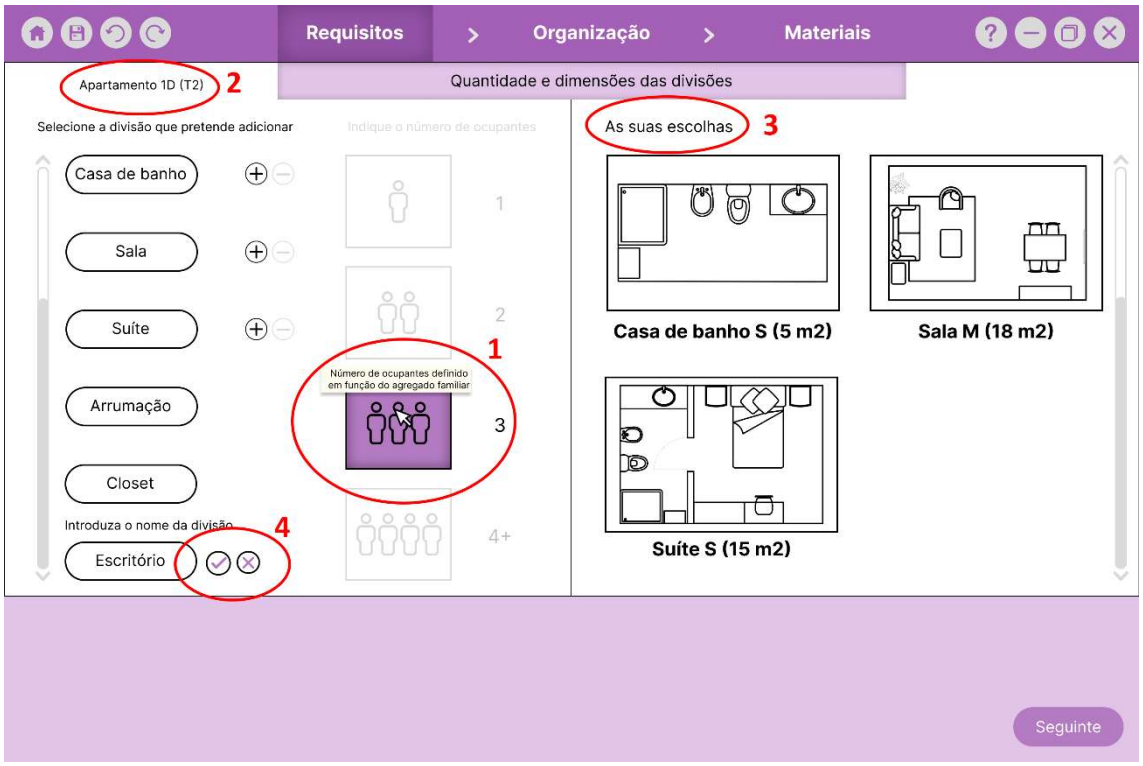


Figure 125_Refinement of the High-fidelity prototype: Integration of contextual information in the "Requirements" phase. 1: Explanatory note about the number of occupants restriction on common areas; 2: Chosen apartment identification; 3: "Your choices" part of the interface identification; 4: Confirmation and cancellation buttons in the "Customise" room feature.

In addition, several **interface adjustments were implemented to optimise user experience**. A "Start" button was introduced into the initial screen to facilitate user onboarding, and confirmation and cancellation buttons were added to the "Customise" room feature to allow for greater control (Figure 125). Redundant elements were removed to reduce cognitive load. Specifically, the "Help" option on the homepage was removed, given its simultaneous availability in the top toolbar (Figure 126), and the "back" button within the "Building Menu" page was excluded due to its functional overlap with the existing "Home" button (Figure 127).



Figure 126_Refinement of the High-fidelity prototype: Removal of the "Help" option on the Homepage. Left: previous version with the "help" option on the menu of functions and simultaneously on the top toolbar. Right: Revised version with the "help" option removed from the list of functions.



Figure 127_Refinement of the High-fidelity prototype: Removal of the "Back" button on the Building menu page. Left: "Home" and "Back" buttons in the top toolbar with the same function. Right: Revised version with the "Back" button removed.

This interface refinement allowed the improvement of the high-fidelity prototype, to test it with potential end-users, and gather information about the interface's usability and users' satisfaction. Architects also used the prototype to discuss the interface's usefulness in a co-design process for housing customisation. The following sections report the results of the last iteration, which includes the evaluation with inhabitants and the discussion with architects.

5.3.3 Summative evaluation with potential users

Thirty potential users participated in the summative evaluation using the refined high-fidelity prototype. The inhabitants **were not those who participated in the previous evaluation with the low-fidelity prototype and never had contact with the interface, so as not to compromise the results.** As shown in Table 36, participants were between 25 and 45 years old (30% were 25–30 years old, 17% were 31–35, 13% were 36–40, and 40% were 41–45 years old). 50% of them were men and 50% were women. Regarding education, 43% had compulsory education, and 57% had higher education. They consider having a reasonable (37%), good (30%), and very good (33%) relationship with digital technologies, and 77% had never had contact with an architectural project. The participants have different professional or training backgrounds, with a higher percentage (17%) being related to Information Technologies (IT), followed by Health, Customer service, and Administration and management with 13% each.

Participants who had previous contact with an architectural project have mainly a very good relationship with digital technologies. The individuals with training who can enable them to understand technical drawings are a geographer and an HVAC technician, both with a good relationship with digital technologies.

Table 36_Results of the demographic questionnaire applied at the summative evaluation

Age	Numer of participants	Percentage
25-30	9	30%
31-35	5	17%
35-40	4	13%
40-45	12	40%
Gender		
Male	15	50%
Female	15	50%
Other (specify)	0	0%
Education		
Until 9th grade	0	0%
Between 9th and 12th grade	13	43%
Higher education	17	57%
Profession/training		
IT	5	17%
Health	4	13%
Administration and management	4	13%
Customer Service	4	13%
Police forces	3	10%
Humanities	3	10%
Geography	2	7%
Chemistry	2	7%
History	1	3%
Construction	1	3%
Fine Arts	1	3%
Perceived relationship with digital technology		
Very poor	0	0%
Poor	0	0%
Reasonable	11	37%
Good	9	30%
Very good	10	33%
Previous contact with an architectural project		
Had previous contact	7	23%
Never had contact	23	77%
How they feel		
Motivated	28	93%
Apprehensive	1	3%
Other (curious)	1	3%

Similar to the formative evaluation with the low-fidelity prototype, the participants performed predefined tasks to experience the different interface features. The protocol of the summative evaluation is provided in Appendix D, which includes the task script given to the participants to guide them in the interface experimentation, the required steps for each task (which were not given to participants), and the questionnaires applied.

The task script provided to participants was modified from the version used in the formative evaluation. Tasks were added or revised according to the refinements implemented in the interface design. Therefore, in the summative evaluation, **the participants performed ten tasks.** Task 1 consisted of logging in with the access data provided. In task 2, participants were asked to choose a specific apartment in the building floorplan which they would customise. In task 3, the participants start customising the house by selecting a group of rooms and their sizes. Task 4 intended to add a customised room that was not on the list of rooms available to choose from. Task 5 aimed for the

participants to choose one of the library options for the housing layout and then customise it by swapping the position of two rooms. Tasks 6 and 7 are related to editing the connections between rooms. In task 6, the participants should drag a door to a new position, and in task 7, they should remove a wall to connect two rooms. Task 8 consisted of detailing the floorplan by choosing the kitchen and bathrooms' layouts. In task 9, the participants should assign a flooring material to a room. Finally, task 10 consisted of finishing the process of customisation. For that, they should access the page that displays the summary of the choices and the budget information and then submit the project that would appear in the overall floorplan of the building.

During and after the interface experience, a set of questionnaires was applied, including a preliminary demographic questionnaire, a Single Ease Question (SEQ) questionnaire, a System Usability Scale (SUS) questionnaire, and a Graphical User Interface (GUI) questionnaire. The inhabitants answered the **SEQ questionnaire** by rating each task from 1 to 7 (very difficult to very easy) after completing it. Table 37 shows that the tasks were generally considered easy to perform, with mean values above 5.97. Tasks 1, 3 and 10 were the ones considered easier, with mean values above 6,70 and relatively stable evaluations, according to their Standard Deviation values. Task 1 (logging in) was the highest rated, having received an evaluation of 7 from all the participants. On the other hand, Tasks 2, 4, 5, and 9 obtained lower mean (between 5,97 and 6,13) and median values (6 and 6,5). However, these tasks were the ones with higher SD values, indicating that most respondents evaluated them higher, while fewer individuals attributed lower values. Task 2 (choosing the apartment in the building floorplan) had the lowest rate of 5.97 on average and a Standard Deviation (SD) of 1.13. Tasks 6, 7 and 8, related to the permeabilities and detailing design tasks, are in the middle in terms of mean values, although with median and mode values of 7, reflecting a good evaluation.

Table 37_SEQ questionnaire applied during the summative evaluation with inhabitants: Results of each task

Tasks	Mean	SD	Mode	Median
Task 1- Login	7	0	7	7
Task 2- Choose the apartment	5,97	1,13	7	6
Task 3- Selection of rooms and sizes	6,70	0,53	7	7
Task 4- Addition of a customised room	6,13	1,2	7	6,5
Task 5- Choose and customise a house layout	6,10	0,96	7	6
Task 6- Change a door position	6,67	0,61	7	7
Task 7- Removal of a wall	6,63	0,61	7	7
Task 8- Choose kitchen and bathroom layout	6,53	0,63	7	7
Task 9- Choose a flooring material for a room	6,10	1,06	7	6
Task 10- Submit the project	6,77	0,63	7	7

Each task consisted of a set of steps that should be performed to complete it. Similar to the formative evaluation, **the success or failure in carrying them out was registered, as well as the number of attempts made, and the time participants took to complete them successfully**.

As Table 38 shows, all the participants completed all the tasks, although not all did it on the first attempt. Five tasks (namely, tasks 1, 3, 6, 8, and 10) were performed by all the participants in the first attempt. Task 5 was performed in the first attempt by 29 individuals, while Task 2 was completed by 24. Tasks 4 and 9 were each completed in the first attempt by 21 participants. The task with the lowest first-attempt completion rate was Task 7, with only 17 participants achieving success on their first try.

Tasks 6 and 7, both concerning permeabilities, revealed the shortest average completion times and ranked among the three tasks with the lowest standard deviation values. In contrast, Task 2 required the longest average time to complete (36 seconds), although it demonstrated the second-highest standard deviation (13.1), indicating considerable variability in performance. Tasks 1, 3, and 8 also recorded relatively long completion times, ranging from 25.7 to 28.6 seconds. Notably, Tasks 3 and 8 were associated with higher standard deviation values, suggesting inconsistent performance across participants. Task 1, however, had the lowest standard deviation, reflecting a high degree of consistency in execution time. It should be noted that Task 1 was completed on the first attempt by all participants, showing its ease, despite its duration.

Table 38_Results of the observation of task performance by inhabitants in the summative evaluation

	Completed all the steps of the task (Number of participants)	Completed all the steps of the task in the first attempt (Number of participants)	Time average to complete the task (seconds)	SD
Task 1- Login	30	30	25,7	6,3
Task 2- Choose the apartment	30	24	36	13,1
Task 3- Selection of rooms and sizes	30	30	28,6	12,4
Task 4- Addition of a customised room	30	21	23,6	14,7
Task 5- Choose and customise a house layout	30	29	24,9	9,5
Task 6- Change a door position	30	30	8,3	6,5
Task 7- Removal of a wall	30	17	12,4	7,5
Task 8- Choose kitchen and bathroom layout	30	30	26,2	11,2
Task 9- Choose a flooring material for a room	30	21	22,9	9,5
Task 10- Submit the project	30	30	19,7	9,2

After performing all tasks, the inhabitants answered a **System Usability Scale (SUS) questionnaire** with ten questions to evaluate the system's usability. These predefined questions are alternately phrased positively and negatively. Each item is rated from 1 to 5 (totally disagree to totally agree).

Table 39 shows the results of the SUS filled out by the inhabitants. Each item score was calculated based on the mean value from ratings of thirty participants, and their sum was multiplied by 2.5. The SUS calculation method has been previously explained in section 5.1 (Formative evaluation using a low-fidelity prototype). As shown in Table 39, each item score contributed to a total SUS score of 93.18.

Table 39_SUS questionnaire applied during the summative evaluation with inhabitants: Results of each item and the total SUS score

	Mean	Item score
Item 1- I think that I would like to use this system frequently	4,60	3,60
Item 2- I found the system unnecessarily complex	1,27	3,73
Item 3- I thought the system was easy to use	4,73	3,73
Item 4- I think that I would need the support of a technical person to be able to use this system	1,2	3,80
Item 5- I found the various functions in this system were well-integrated	4,63	3,63
Item 6- I thought there was too much inconsistency in this system	1,27	3,73
Item 7- I would imagine that most people would learn to use this system very quickly	4,67	3,67
Item 8- I found the system very cumbersome to use	1,10	3,90
Item 9- I felt very confident using the system	4,67	3,57
Item 10- I needed to learn a lot of things before I could get going with this system	1,10	3,90
Sum of item scores = 37,27		
SUS score (sum of item scores x 2,5) = 93,18		

The participants also filled out a **Graphical User Interface (GUI) questionnaire**, rating positively and negatively phrased statements from 1 to 5 (totally disagree to totally agree). The GUI questionnaire consisted of nine statements related to aspects of the interface. As Table 40 shows, the positive statements had mean values above 4.53, and the negative statements had mean values of 1.13, except statement 4, which had a 1.37 mean value. The evaluations are relatively stable across the respondents, and the positively phrased statements have higher Standard Deviation values than the negatively phrased statements.

Table 40_GUI questionnaire applied during the summative evaluation with inhabitants: Results of each statement

	Mean	SD	Mode	Median
1- I understood the names of the project phases	4,67	0,61	5	5
2- It is not easy to navigate through the menus	1,13	0,35	1	1
3- I understood the menu options and indications	4,63	0,67	5	5
4- The menu icons and buttons do not clearly indicate their function	1,37	0,56	1	1
5- The diagrams are easy to read and understand	4,77	0,50	5	5
6- The graphic design of the screens is not well-designed	1,13	0,43	1	1
7- The information is well organised on the screens	4,53	0,68	5	5
8- It's not easy to access the information I need	1,13	0,35	1	1
9- The buttons and text sizes are appropriate	4,73	0,64	5	5

Finally, participants were asked to list the **interface's three strongest and weakest aspects** in their opinion. The results were grouped according to identical aspects. Figure 128 shows the participants' answers regarding both weaknesses and strengths.

Twelve **strong aspects** were mentioned. Fifty-seven per cent of the inhabitants said the tool is user-friendly, describing it as intuitive, simple, and easy to use. They also mentioned (53%) the fact that they can make their own choices in different design phases. Other aspects mentioned as positive were: i) the double visualisation mode as the floorplan and 3D model (37%); ii) the direct interaction with the design and seeing the results in real-time (30%); iii) the budget information (30%); iv) the

predefined options to choose from (23%); v) the interface's graphical design being clean without too much information (23%); vi) the system warning if user's choices are not feasible or have relevant consequences, and suggests a solution (10%); vii) the potential to ease the dialogue between architect and client, as it allows the inhabitants to translate the house they imagine into reality (7%); viii) the potential to be used in refurbishments (3%); ix) the order of the design phases is clear (3%); x) the pulsing sentences catch the attention (3%).

Regarding **weak aspects**, which are missing or could be improved, ten were mentioned. Thirteen per cent of the participants said that the scrollbar in the definition of household requirements does not stand out. They also said they would like to be able to customise specific measurements, such as kitchen cabinets (10%). The fact that the options were not all visible on the screen (when defining the requirements), because they needed to scroll down the scrollbar to see more options, was also pointed out as an aspect to improve (7%). The remaining weak aspects were each mentioned by only 3% (one person). Such aspects are: i) the system could simulate how the furniture of specific stores would look in the space; ii) the "+" to add rooms may not be clear to people who do not have much digital literacy; iii) an option to add walls is missing; iv) the instruction sentences do not stand out; v) removing walls should be done just by directly click on them without having to activate a button first; vi) when is not possible to choose the number of occupants this option should not appear; and finally, one person think vii) it is not necessary to choose the number of occupants of the household.

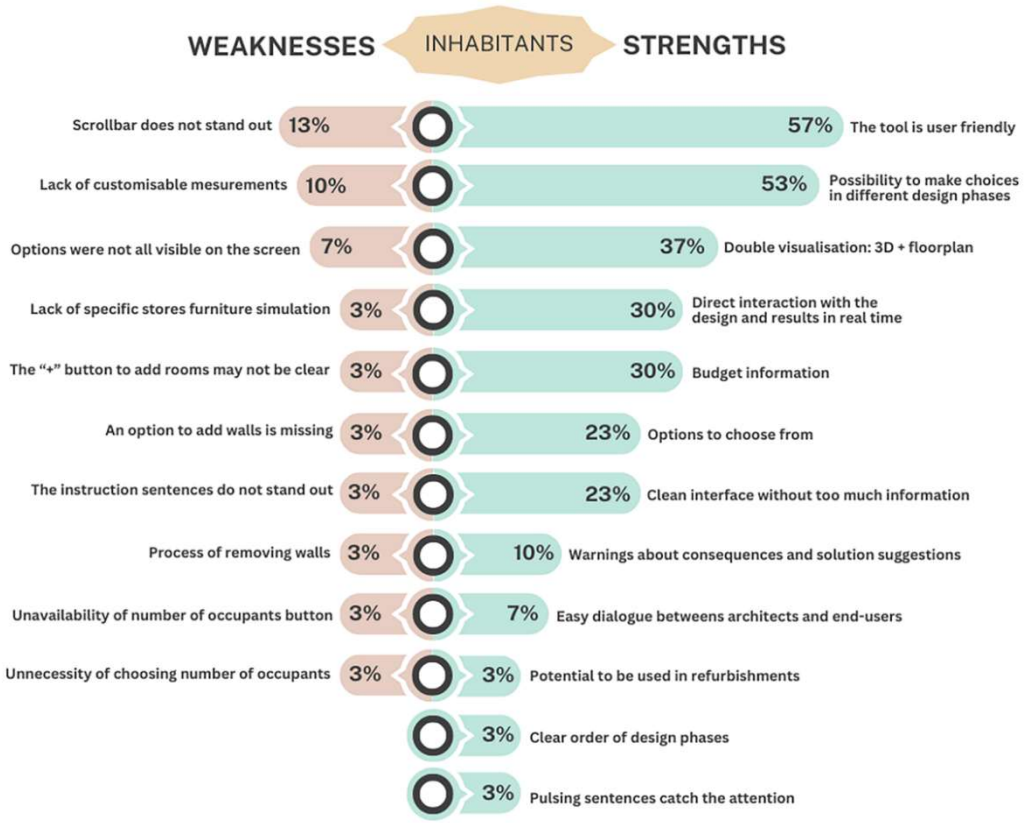


Figure 128_Overview of the weaknesses and strengths identified by the inhabitants during summative evaluation

5.3.4 Discussion with architects

Ten architects used the interface, performing the same ten tasks while playing the role of inhabitants to experience how they would participate in the definition of their own houses. Then, they gave their opinions from their expert viewpoint.

After performing all tasks, architects were asked to identify strong and weak aspects of the system. As shown in Figure 129, a total of thirteen **positive aspects** were mentioned. The ones that stand out are: i) clear representation of the architecture through the floorplan and 3D model (identified by 70% of architects); ii) clarity, ease, and speed of use (60%); and iii) choices informed by the budget (60%). Other aspects mentioned include: iv) there is flexibility by allowing to choose between several options at different stages (30%); v) direct interaction with the project and results in real-time (20%); vi) sequence of tasks is correct (20%); vii) has the potential to be adapted to other participatory contexts (20%); viii) allows the design of customised houses because the inhabitants are the ones who make the choices (20%); ix) the interface's graphical aspect is clear (10%); x) can be used by people with little digital literacy (10%); xi) the ability to choose the number of occupants and room's size (10%); xii) does not require technical knowledge but still creates regulatory-appropriate solutions (10%); and xiii) makes inhabitants think about their priorities in managing the room's sizes (10%).

Regarding **negative aspects**, eleven aspects were identified regarding two subjects: (1) the interface and (2) the system itself. Regarding the interface, architects mentioned that: i) the instruction phrases, despite pulsing, do not stand out (40%); ii) the representation of site context is missing (10%); iii) the floorplan representation should be bigger (10%); iv) the buttons to edit doors and walls should be more visible (10%); and v) when choosing the apartment, there should be tabs identifying the building floors (10%).

Regarding the system itself, they think that: i) it limits the architect's work since it only allows them to define the general characteristics of the building and shared spaces, but not the interior of the houses (20%); ii) requires from the inhabitant the ability to have full knowledge of space when choosing the rooms' size (20%); iii) is restrictive, as choices are conditioned only to the predefined options (20%); iv) only allows working on conventional architectural models, as the pre-defined options do not support projects with particular characteristics (20%); v) It can only be used when the end users are known before the construction (10%); and vi) the flexibility should not interfere with the budget (10%).

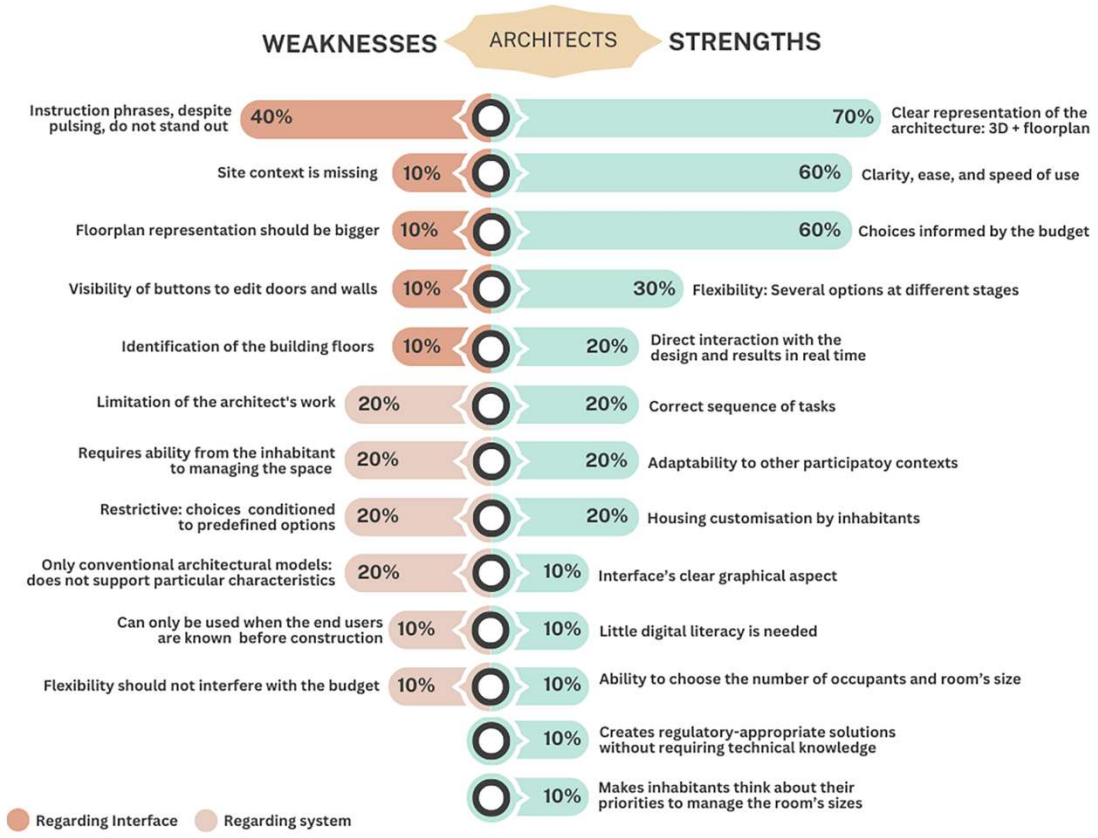


Figure 129_Overview of all the weaknesses and strengths identified by the architects during summative evaluation

5.3.5 Findings

The evaluation described in the previous sub-chapters revealed three main findings regarding the inhabitants' assessment, and four main findings regarding the architects' opinions about the interface proposed.

Regarding inhabitants, one of the findings is that (1) **the interface refinement contributed to both perceived and observed improvement of the interface usability and end-users' satisfaction**, as suggested by the results of the observation measures, and the SUS, GUI and SEQ questionnaires. Another finding is that (2) **the interaction with interface elements is influenced by the sequence of preceding tasks, while the visibility of those elements and ambiguity in task instructions were found to interfere with usability**, as observed through the participants' task performance. Finally, (3) **the proposed interface is capable of addressing inhabitants' needs and supporting their collaboration in the design process**, as evidenced by the efficacy measure, and reinforced by participants' reports of the interface's perceived strengths.

Regarding architects, the findings suggest that (1) **architects consider the interface user-friendly and capable of supporting informed decision-making**, as evidenced by the strengths mentioned by them. Moreover, (2) **they consider the interface relevant to the architecture design process** since it

allows involving end-users in the customisation in different phases of the design process with flexibility of choices. However, (3) **architects find the tool restrictive**, with flexibility influenced by predefined options and its applicability only for specific situations when the end users are known before the construction. Finally, another finding was that (4) **architects expressed concern that their professional role may be devalued**, as reflected in the weak aspects they identified, where they perceived the interface as constraining their contribution.

The high ratings obtained from the **inhabitants' evaluation** suggest that the proposed interface is accessible to its potential users and capable of addressing their needs. Following two iterative interface refinements, **the overall System Usability Scale (SUS) score increased** compared to the formative evaluation conducted with the low-fidelity prototype. Also, **the responses to negatively phrased items in the Graphical User Interface (GUI) questionnaire showed lower values**, indicating enhanced user satisfaction. Specifically, statement 4 ("The menu icons and buttons do not clearly indicate their function") and statement 6 ("The graphic design of the screens is not well-designed"), which previously reflected areas of lower satisfaction, were re-evaluated positively after the refinements. These elements were subsequently perceived as strengths of the interface, with participants describing it as clean, intuitive, and user-friendly.

The user-friendliness of the interface is further supported by the results of the Single Ease Question (SEQ) questionnaire, which evaluates the perceived ease of task completion. The findings indicate that **all participants successfully completed the assigned tasks**, although not all were accomplished on the first attempt. Particularly, **refinements to the interface led to improved performance in tasks** related to permeabilities definition. These tasks received higher ratings in terms of perceived ease, as measured by the SEQ, than previous evaluations, and also demonstrated superior efficiency, with tasks 6 and 7 completed in less time than any other task. The enhancement of interface flexibility, particularly in the sequence for repositioning doors (task 6), has contributed to this outcome. Observational data revealed that most participants intuitively dragged the door without first activating the designated button. Given that the refined interface supports this interaction, the task was considered successfully completed on the first attempt.

In contrast, despite task 7 (removal of a wall) revealed high efficiency, only 17 participants completed it on their first attempt. Those who did not succeed initially tended as well to click directly on the wall without first activating the wall removal function. This behaviour may be attributed to the **influence of the preceding task**, which did not require activation of a specific function before direct interaction with the floorplan. Task 2, which received the lowest ease-of-use rating and was the longest in duration, was completed on the first attempt by 24 participants. This outcome may be explained by the nature of the interaction required, which differed from the drag-and-drop mechanism employed

in subsequent tasks that were more favourably rated. Task 2 involved a different sequence of actions, potentially contributing to its lower perceived ease and performance.

The challenges that hindered some participants from successfully completing certain tasks on their first attempt, namely, task 4 (addition of a customised room) and task 9 (assignment of flooring material to the living room), each completed initially by 21 participants, are primarily related to **limitations in interface elements visibility and ambiguity in the task instructions**. For task 4, the difficulty stemmed from the lack of prominence of interface elements, such as the scrollbar required to access the option for adding a customised room. In task 9, participants were instructed to select the "first wooden floor material," which led to confusion regarding the interpretation of "first." Many initially selected the "tiles" option, as it appeared first in the material list, rather than clicking on the wooden floor category and selecting the first item within the opened window with the available options. Upon a second attempt, participants correctly completed the task as intended.

Despite the aforementioned difficulties, all tasks were ultimately completed by participants, in contrast to the initial evaluation, where only five tasks were successfully completed by all participants (see Table 34 in sub-chapter 5.1). Completion time varied across tasks, yet all were finalised within a reasonable timeframe, indicating overall ease of tasks and interface usability. Regarding strengths and weaknesses, **inhabitants** highlighted aspects related to the interface itself (graphic appearance and user-friendliness both in terms of interaction and visualisation) and how **the interface helps them to participate in the design process** (being able to make their own choices, having predefined options to choose from instead of creating from scratch, system warnings about feasibility, budget information, etc.). On the other hand, i**nhabitants had difficulty mentioning something as a negative or missing aspect**. Even so, they mentioned **difficulties carrying out the tasks** (e.g., interface elements that were not visible) and the lack of features they would like the interface to include (e.g., simulating furniture and customising measurements).

The **discussion with architects** also allowed me to take some insights regarding the interface and their opinion on its relevance for the architecture practice within participatory and collaborative contexts.

Similar to inhabitants, **architects** highlighted that **the interface is user-friendly, the clear representation of the architecture through the floorplan and 3D representation, and the budget information**. Indeed, computer-aided design tools are used by designers to assist in their task of creating design solutions. However, their graphical user interfaces can be complex for non-designers who have not received training to manipulate them. Thus, this thesis proposes a graphical user interface to assist and guide inhabitants in a complex design decision-making process by presenting options to choose from rather than asking them to manipulate design tools to create solutions from scratch. Based on a simulation of a generative system, the interface presents the options and

implications of choosing such options, acting as a design assistant. These aspects were considered in the interface design development to comply with the requirements derived from the interviews, and in fact, they were a positive aspect highlighted by the inhabitants during both the formative and summative evaluations.

Regarding the weaknesses mentioned by the **architects**, despite saying that the system is adaptable to other contexts and pointing out **flexibility as a positive aspect** (as it allows choices to be made in various design phases), **architects find the tool restrictive**. They state that **choices are conditioned by predefined options** and that these options do not support projects with particular characteristics. Although this statement by architects is correct, the interface for mass customisation of houses defined in this study focuses on middle and low-income households. Therefore, this research proposes that such projects have regular characteristics and that a couple of options are available for inhabitants to customise their houses. The interface is thus not foreseen for design projects with particular characteristics, such as when a private client chooses an architect for a tailor-made design. Nevertheless, in the proposed interface, constraints are defined by the architects, and the generative system embeds their knowledge and experience, including construction regulations. Capturing designers' knowledge in a generative design system allows users to explore various design options that respect formalised design rules and construction regulations (Kwieciński & Słyk, 2023). The interface acts as a design critic, as in Frazer's approach to Segal's method (Doe, 2018), or in HOPLA-Home Planner (Kwieciński & Słyk, 2023), by evaluating the implications of users' choices based on the design rules and presenting them with possible solutions.

On the other hand, **architects** state that flexibility should not interfere with the budget. According to Khalili-Araghi and Kolarevic (2018), flexibility for customisation does not sacrifice efficiency and affordability if constraints are defined. The authors argue that these constraints can be standard predefined options that, when combined, allow for affordable customisation. Architects also mentioned that **the system can only be used in projects where end-users are known before the construction**, so that they can participate in the design process. In fact, the tool was defined for a collective housing context, focusing on apartment projects for housing cooperatives. Still, this is just a context in which the users are previously known and can be applied to other situations, such as in a public initiative, with the relocation of specific communities. By proposing such a co-design system, this research also propose that in some social housing developments, the housing attribution system starts before the building construction, so that the households can have a say in their future houses.

Architects consider that the system limits their role as they are not the ones to define the interior of the dwellings. In the proposed approach, aligned with participatory co-design practices, the architect's role is not to create each specific house design but to provide the framework and design rules for users to create customised designs. Architects define the family of possibilities rather than

each design itself. Furthermore, in the housing co-design system presented, the architect is the one who defines all the characteristics of the building, including the relationship with the geographical and cultural contexts, and also defines the various conditions and inhabitants' choice possibilities. The designed interface is intended to facilitate the process of customising multiple dwellings within a single building, thereby addressing the diverse needs of individual end-users. This approach enables a scalable solution to customisation that would otherwise be impractical for architects to manage on a household-by-household basis. As stated by Habraken (1986), the architects' mission is to feed the living environment to contribute to its spontaneous development. With the proposed system, the architect provides the inhabitants with the means to customise themselves in a feasible and informed way. The conditions defined by the architect are what will feed the generative system to present options to the inhabitants according to their choices, which means that the architect's work is highly necessary and valued.

This discussion leads to the debate on authorship and stakeholders' roles in participatory and co-design processes. As discussed in the literature, the notion of authorship has been diluted with the development of collaborative digital tools and new ways of practising architecture, such as participatory design (Carpo, 2013; Picon, 2016). In such a view, authorship is shared between the architect, who defines the conditions, and the end-user, who customises the design (Picon, 2016; Eloy and Vermaas, 2022). The architect's role is to facilitate the process and give end-users the means to achieve a customised solution.

Despite this, one can say that architects consider the proposed system relevant to the practice of architecture involving end-users. They value the flexibility of choices so that the dwellings are truly customised. However, they fear being devalued because they do not understand the importance of their role in the process. For architects to value participatory and co-design processes, they must understand the importance of their participation, which is significant but different from what they are traditionally used to. Until architects gain awareness of how digital processes can be involved in the design, they will resist this type of innovation and not recognise their relevance.

CHAPTER 6: Conclusion

This chapter provides a reflective synthesis of the research questions, objectives and outcomes explored throughout the thesis. The research questions and hypotheses formulated are re-examined in light of the findings presented in the previous chapter. The discussion highlights the main theoretical and practical contributions of the study, and acknowledges its limitations. Finally, potential directions for future research are outlined.

6.1 Research overview

This thesis investigated the potential of using digital tools in the co-design of customised housing. It was discussed that the meaningful involvement of end-users in shaping the spaces they inhabit is fundamental to ensure that the built environments genuinely reflect their needs and aspirations, thereby fostering a deeper sense of satisfaction, particularly within the context of collective and mass housing.

Although participatory processes have long been recognised within the discipline of architecture, genuinely collaborative approaches, particularly in the context of housing, remain comparatively scarce. This scarcity can be attributed to both the inherent complexity of such endeavours and to a prevailing reluctance to transfer authorship and decision-making power regarding aspects of architectural design to non-designers. On the one hand, effective collaboration requires mechanisms that enable residents to participate meaningfully, despite their limited technical knowledge and difficulty in articulating their preferences and needs. On the other hand, the rise of computational tools in architectural practice over the past decades has sparked ongoing debates about authorship and the distribution of creative agency.

Digital tools offer significant potential to enhance spatial understanding among non-specialists by providing interactive and realistic visualisation modes. These tools also enable users to simulate and evaluate the outcomes of design decisions in real-time. Moreover, generative design systems are able to address customisation within collective and mass-housing contexts, enabling the creation and validation of a wide range of design possibilities tailored to the specific needs of diverse users.

However, the digital tools currently available in academic literature and commercial markets are either intended for professional use and do not encompass the integral knowledge, e.g., regulatory frameworks, to support architectural design undertaken by non-specialists. Moreover, when intended for broader audiences, their user interfaces do not support an iterative development process with close contact with end-users from the initial stages of development. Therefore, the requirements for

an interface that facilitates a natural interaction with architectural designs dedicated to users with little experience in architectural design processes remain understudied.

This thesis proposes a validated natural user interface that, coupled with a generative design system, aims at empowering future residents of multi-family housing developments, such as housing cooperatives, to engage with the architectural design of their houses in a viable and informed manner. The research focuses on the development of a graphical user interface that serves as a bridge between inhabitants and architects via the generative design system. The interface design process is grounded in user-centred design methodology, which informs the definition of requirements and guides the development and testing of a graphical interface tailored to residents and incorporating the identified requirements.

Chapter 2 examines strategies previously implemented to foster participation in architecture and housing customisation, and reviews a selection of computer-mediated participatory design tools for customising housing designs. This review provided the options presented to inhabitants during the interviews, described in Chapter 3, based on which some interface requirements were gathered. Furthermore, Chapter 3 presents empirical data on the operational dynamics of Portuguese housing cooperatives, exploring how participatory processes currently function both within these institutions and in other projects held by architects, and how they might be enhanced through the use of a digital co-design tool. The findings informed the specification of a graphical interface, which was subsequently designed and tested.

The interface design (Chapter 4) and the simulation of a practical case study enabled potential users to interact with a prototype of the interface (Chapter 5). The iterative process of defining, developing a prototype, and testing the interface across four cycles allowed for progressive refinement, ensuring the interface became accessible to its intended users and capable of supporting their engagement in architectural design.

Chapter 5 also demonstrates the results of the summative evaluation, underscoring the potential of the proposed interface, demonstrating its capacity to facilitate the co-design of customised housing, and respond to the research questions, as elaborated in the following section.

6.2 Discussion: How a digital tool can enhance Co-design processes for housing customisation

This sub-chapter discusses the content and the potential impact of the proposed digital interface for the co-design of customised housing, focusing on the response to the research questions and the validation of the formulated hypothesis. It also explains how the research conducted contributes to achieving the stated goals.

6.2.1 Answering the research questions

Three research questions were formulated in Chapter 1. This section discusses how the research conducted addresses each of them.

(RQ1)

Which requirements should a digital housing design tool meet to effectively support end-user collaboration?

To address this research question, the following hypothesis was formulated:

> ***(H1) The requirements for enabling effective end-user collaboration through a housing digital tool can be collected by using a user-centred design methodology:*** *The gathering of information from direct contact and empathy with potential end-users allows for the definition of user requirements aligned with their needs.*

These requirements are closely tied to facilitating the decision-making process. Specifically, data collected from the interviews suggest that the envisaged tool should **empower users to engage with housing design from the earliest stages**, such as defining the functional program and configuring spatial layouts and their connections, rather than limiting their involvement to superficial decisions at later phases, such as selecting finishing materials or making minor adjustments to pre-established designs. Interviews with professionals revealed that few genuine collaborative design processes are practised, especially in collective and mass-housing contexts. The professionals acknowledge that architects are reluctant in transferring their role of designers to non-specialists in architecture. In contrast, the literature discusses the concept of shared authorship, emerging collaborative approaches to architectural practice, including participatory design and the introduction of digital technologies that enable collective engagement (Carpo, 2013; Picon, 2016). Scholars also advocate for the early involvement of end-users in the design process, enabling them to actively formulate their own design proposals (e.g., Münster et al. (2017) and Faliu et al. (2018)).

In the context of multi-family housing, interviews with housing cooperatives, alongside the first phase of interviews with inhabitants, indicate that residents currently engage in decision-making primarily through voting on pre-prepared proposals or by individually requesting minor design modifications. However, findings from the second phase of interviews reveal a clear dissatisfaction as inhabitants expressed a desire for greater involvement during the early stages of the process and reported feeling that the voting system provides minorities little influence over design decisions. This underscores the need to accommodate **individual participation** from all residents, recognising that each household has distinct needs that cannot be addressed through collective voting or consensus-based discussions. The literature on this subject reveals contrasting perspectives, as some scholars advocate for consensus-building (Marschall, 1998; Sanoff, 2000), while others emphasise the

importance of supporting different decisions, going beyond voting or consensus-based approaches, thereby acknowledging and accommodating the diversity of user needs (Rescher, 1995; Miessen, 2011);

In terms of architectural design, the results of interviews with architects suggest that an effective co-design tool should offer **viable design solutions** grounded in predefined parameters and prepared by architects, serving as a foundation for user-led refinements. This is based on the architects' opinion that inhabitants lack the technical knowledge to design themselves, which is supported by the literature (Van Der Linden et al., 2018), where is discussed that architects consider they must present alternatives to inhabitants.

Interviews with inhabitants also demonstrate their preference for the interface to **present a viable set of options through visual representations**, rather than requiring inhabitants to draw from scratch. Accordingly, the literature (Brandt, Binder and Sanders, 2013; Franke and Hader, 2014) advocates for the integration of toolkits of pre-defined options represented by visual elements and 'making' activities that allow users to express preferences through direct manipulation of design components. This aligns with Noguchi & Hernàndez-Velasco (2005) proposal of 'mass-custom design', which allows inhabitants to combine predetermined housing elements to create customised solutions. The proposed interface integrates these last couple of requirements through a library of options in each design phase, such as alternative spatial configurations or material finishings. To ensure accessibility, the interface employs clear, non-technical language and interactions. For example, using relative size indicators (e.g., S/M/L) instead of precise measurements (e.g., dimensions or area) can be used so as not to require technical knowledge. Nonetheless, the feedback collected in the formative evaluation suggests that such simplified indicators should be supplemented with these measures to provide contextual information to support informed decision-making.

Another critical requirement recommended by architects during the interviews is the provision of **real-time visual feedback and guidance throughout the design process**. These features are paramount for maintaining architectural viability and supporting users who may lack technical expertise or the ability to anticipate the implications of their choices. The visualisation of results in real time, warnings about consequences and suggestions were highlighted as positive aspects of the interface, both in formative and summative evaluations with inhabitants and architects, which underscores the importance and validation of these requirements. Accordingly, the literature highlights the meaningful learning through direct experience, through the experiential learning approach, i.e., experimentation in simulated environments (Dewey, 2008; Kolbe, 1984; Peerapun, 2012). Some authors, such as Mcleish (2003), Khalili-Araghi & Kolarevic (2018), and Kwieciński & Słyk (2023) also recommend the application of generative and algorithmic design strategies to automate the validation of user inputs and provide real-time feedback.

Finally, the second phase of interviews with inhabitants suggests the use of **diverse perspectives** to enhance their spatial understanding. This was addressed in the interface proposed by combining semi-immersive 3D representations with annotated floorplans for precision, as found to be preferred by inhabitants in the third phase of interviews. Realistic representation of architecture was also mentioned by professionals as one of the main potentials of digital technologies. Furthermore, enabling direct manipulation of specific design elements within the digital interface fosters a sense of ownership and customisation, allowing users to interactively shape their living environments. The literature also advocates for the use of diverse representation modes, including map-based interactions that simulate natural actions observed in traditional participatory sessions (Botero and Saad-Sulonen, 2008, 2010; Nuojua *et al.*, 2008), as well as immersive and realistic 3D environments that enhance spatial perception among laypeople (Al-Kodmany, 2001; Schroth, Wissen and Schmid, 2006; Salter *et al.*, 2009; Münster *et al.*, 2017). However, although the recommendations for immersive environments, the interviews with inhabitants revealed their preference for accessible devices such as a computer, limiting the immersion to their screens. Nevertheless, other types of interfaces such as HMDs may be used in other participatory contexts (e.g., face-to-face workshops) to enhance the immersion and feeling of presence. Additionally, online map-based solutions can also be used to foster bidirectional communication in participatory approaches for urban development and management.

While existing digital design systems in both research and commercial contexts are unsuitable for inhabitants, as they do not comply with some of the mentioned requirements, the empirical evaluations conducted throughout this research further validate these requirements and their use in the proposed interface. These systems are either primarily oriented towards professional use and do not embed the architectural rules or regulatory constraints required to support non-experts, or tools aimed at wider audiences similarly lack mechanisms to ensure feasibility, risking misleading users. Professional software rely on complex interfaces and free-form modelling, offering neither guidance nor constraints to prevent unviable solutions, making them only suitable to whom has the appropriate expertise. Plug-ins or lightweight applications of these systems for tablets or smartphones are also not suitable since inhabitants expressed a clear preference for computer-based interaction over mobile alternatives. **A standalone interface was therefore necessary to ensure that all requirements identified were simultaneously met**. The interface developed in this research was designed to meet the requirements identified with inhabitants and professionals, such as offering predefined viable options, providing real-time feedback and guidance, and supporting step-by-step decision-making. Empirical evaluations confirmed its accessibility for non-experts. Specifically, formative assessments involving inhabitants (section 5.1), as well as summative evaluations conducted with both inhabitants

(section 5.3.3) and architects (section 5.3.4), consistently identified these features as strengths of the proposed interface, thus validating the hypothesis presented to address this research question.

(RQ2)

How effectively **can digital housing co-design tools enable inhabitants to interact with architectural design in an informed manner to realise customised housing?**

The results of the summative evaluation with potential users (section 5.3.3) respond to this research question and support the following hypothesis:

> ***(H2) Digital tools enhance collaboration between inhabitants and architects in housing projects by enabling residents to actively participate in design decisions:*** *Using digital technologies improves the end-user understanding. Therefore, they have the potential to enhance inhabitants' collaboration in the design process, through a natural interface that allows them to easily interact with the design of their houses.*

The high ratings of the perceived ease of tasks confirm that the inhabitants can easily interact with the architectural design of houses. Although the SEQ questionnaire did not achieve a full score across all tasks, the results are nonetheless very close to the optimal scenario. Furthermore, despite the majority of participants having no prior experience with architectural projects, the task performance observations indicate that potential users were able to interact with the design interface with ease. These findings reinforce the interface's usability, as evidenced by the fact that all tasks were completed by all participants, each within less than 30 seconds. It is worth noting that in a real-world context, task completion times may be longer, given that the experimental script predefined the options to be selected. In a real scenario, users would likely explore various alternatives before choosing their preferred option.

Despite some limitations, the interface was widely considered user-friendly both by inhabitants and architects, and demonstrated very good performance in assisting users to customise a dwelling within a predefined scenario. The SUS questionnaire further supports the hypothesis under investigation, having earned an excellent usability score in accordance with established literature (Brooke, 1995). The interface's user-friendliness was also emphasised regarding graphical aspects, such as "a clean interface without too much information", as mentioned as a strong aspect of the interface. The findings from the GUI questionnaire further highlight the importance of visual clarity and support for user understanding, such as the presented diagrams with architectural advice (as demonstrated by the high ratings on the fifth GUI statement: "Diagrams are easy to read and understand"). This capacity to support informed decision-making was also recognised as a strength, with responses referring to the "double visualisation", "results in real time", "budget information", and "warnings about consequences and solution suggestions".

Supported by these findings, one can confidently assert that the use of digital technologies, specifically a graphical user interface designed in line with defined requirements, enhances collaboration between inhabitants and architects in the customisation of housing by enabling natural and easy interaction with architectural design.

(RQ3)

What are the benefits and limitations of inhabitants using a digital design tool in the scope of a co-design process and definition of customised housing?

Regarding this research question, it was hypothesised that:

> ***(H3) The use of digital tools in the co-design of housing, by enabling housing customisation, contributes to end users' satisfaction in both the design process and the resulting house designs:*** *Digital tools can enhance end-user satisfaction with the design process by facilitating collaboration between architects and inhabitants. By enabling housing customisation, these tools contribute to end-user satisfaction with the final outcomes of the house designs.*

The impact of using such a tool is reflected in the inhabitants' satisfaction regarding the process and the outcome of their house design. As the literature shows, end-users taking part in the design process of their living environments leads to greater satisfaction (Davidson *et al.*, 2007; Önder, Köseoglu and Bilen, 2010; Elizondo, 2024). However, this hypothesis cannot be fully supported since the interface was not tested in a real-world context, and thus, it cannot be affirmed that the developed interface enhances end-user satisfaction with the design outcome. However, the developed interface has this potential, since, as seen in the response to the previous research question, it allows end-users to easily interact with the design and, thus, customise it.

Furthermore, one can affirm that it enhances their satisfaction with the design process. This is supported by the data collected from inhabitants and architects in the summative evaluation. For example, the SUS score shows inhabitants' satisfaction regarding the process through the high ratings on statements such as Item 1 ("I think that I would like to use this system frequently"). Also, multiple strengths were identified. One of the user requirements was the possibility for inhabitants to make decisions about the design of their houses, and when experimenting with the interface, the inhabitants highlighted this as one of the primary strengths of the interface, underscoring their satisfaction. Architects also mentioned the house customisation made by inhabitants as a strength.

Therefore, the primary benefit of using the proposed interface in the scope of a co-design process is the genuine customisation of houses by inhabitants. Other benefits widely expressed by both groups are related to the support given to inhabitants during the decision-making process. Specifically, most architects highlighted the clear representation of architecture through the dual visualisation mode, the ease and speed of use, and the choices informed by the budget. Additional notable strengths of

this approach include the correct sequencing of design tasks and the ability to generate regulatory-compliant solutions without requiring technical expertise.

The research findings are conveyed in the following benefits:

- Genuine customisation, enhancing end-user satisfaction with the design process, which, according to the literature, leads to higher appropriation and satisfaction with the houses.
- Informed decision-making
- Viable design outcomes without requiring technical knowledge
- Ease and speed of use, and little digital literacy required

On the other hand, some limitations were also identified regarding using the proposed interface in a co-design process for housing customisation. According to inhabitants, the lack of flexibility in customisation is a limitation, such as, e.g., the limited ability to move walls and customise kitchen measurements. Architects also identified flexibility, along with other limitations, although these were also considered as strengths, as described below:

- Flexibility: on the one hand, such a tool allows for flexibility by providing diverse options at different stages. On the other hand, flexibility was identified as a weakness, since the choices are conditioned to predefined options.
- Adaptability: The interface was considered to be adaptable to other participatory contexts. On the other hand, this was also identified as a weakness for supporting only conventional architectural models and accommodating only situations where end-users are known before construction.
- Space management: architects considered that, on the one hand, using a digital tool for the co-design of housing requires the ability of the inhabitants to manage their spatial perception, when choosing the rooms' areas, emphasising it as a weakness. On the other hand, this was considered a strength since it makes inhabitants think about their priorities.

In summary, the limitations identified are largely dependent on contextual interpretation. Although the architects' observations are valid, they pertain to scenarios that fall outside the intended scope of the proposed framework. For instance, the fact that the interface is designed for use in situations where residents are known prior to construction is not a limitation, as the tool was explicitly envisioned for such contexts.

Therefore, the most significant constraint in the use of this digital tool for housing co-design lies in the attitudes and perceptions of the stakeholders involved. The view held by some architects (that the use of such a tool limits their role) reflects a pre-established notion rooted in traditional architectural practice. For the adoption of this type of tool to be successful, it is essential that the

conventional model of architectural practice be re-evaluated, and that architects recognise the evolving nature and importance of their role within participatory and collaborative design processes.

6.2.2 Addressing the research goals

This section explains how the research undertaken addresses the research goals presented in Chapter 1:

(G1) Define the requirements that enable inhabitants to co-design their houses.

(G2) Define and test an interface solution for the co-design of housing, focusing on the user experience.

(G3) Gather the perspectives of architects and inhabitants on collaborative house design, particularly in relation to utilising the proposed graphical user interface.

The first research goal (G1) is addressed in Chapter 4, which builds upon the literature review established in Chapter 2 and the empirical evidence presented in Chapter 3. The review of computational systems for housing co-design developed in Chapter 2 facilitated the identification of relevant design tasks, as well as various modes of visualisation, interaction, and devices, which were subsequently introduced to inhabitants during the third phase of the interview process. Chapter 3 further contributed to the definition of necessary design tasks by examining participatory practices reported by professionals, which highlighted both their accomplishments and the challenges encountered. Insights from interviews with housing cooperatives and residents revealed opportunities to enhance existing practices through the integration of a digital tool for collaborative design. Chapter 4, particularly Section 4.2, synthesises these findings on user requirements, encompassing both functional and non-functional dimensions.

The second research goal (G2) is addressed in Chapters 4 and 5. Drawing upon the user requirements previously established, Chapter 4 introduces a framework for the participatory co-design of housing by inhabitants. As detailed in Section 4.3, this framework encompasses the identification of architectural elements with which users engage (such as spatial layout, walls, doors, and finishing materials), as well as the structuring of the design task sequence. Furthermore, Section 4.4 delineates the components of the Graphical User Interface (GUI), specifying the modes of visualisation and interaction in each design task.

The proposed framework advocates for the integration of the GUI with a generative design system, thereby embedding architectural expertise into the process and enabling inhabitants to engage meaningfully in a democratised design environment. Although the generative system itself was not developed, its conceptual role informed the development of the GUI, which was iteratively designed, assessed, and refined, complying with a User-Centred Design (UCD) methodology.

Chapter 5 addresses this iterative process, which involved different rounds of evaluation using both low and high-fidelity prototypes. These evaluations engaged diverse stakeholder groups, including UX/UI specialists, potential end-users (across two distinct phases of design development), and professional architects. Feedback from these sessions was instrumental in refining the interface, guided by usability metrics, satisfaction assessments, and qualitative insights.

The third research goal (G3) is addressed in Chapters 3 and 5. Chapter 3 presents the perspectives of both professionals and end-users regarding the potential of a digital co-design tool to improve user participation in the architectural design of their houses. Following the development and testing of the prototype, Chapter 5 describes further insights, particularly regarding the use of the proposed digital interface.

Qualitative data were collected through open-ended questions that explored perceived strengths and weaknesses of the interface, based on participants' experiences with the digital prototype. The findings synthesise the level of satisfaction expressed by inhabitants concerning both the interface and the participatory design process it enabled. Additionally, the views of architects were examined, highlighting perceived benefits and limitations of such a tool within professional practice, as articulated from the viewpoint of architectural expertise.

6.3 Final considerations

6.3.1 Thesis Contributions

The main innovation of this research focuses on the fact that a user-centred design methodology was adopted in the design of a Graphical User Interface for housing co-design. The requirements were extracted from direct contact with potential users through interviews, and an iterative process of assessment and refinement was employed. In this way, the interface directly incorporates users' input, responding better to their needs and preferences. By adopting a user-centred design approach, the proposed interface bridges the gap between designers and end-users, allowing for the creation of genuinely customised houses.

Architectural research was combined with a well-established research methodology, usually adopted in information systems sciences, to solve an identified problem in the architectural field. Using a User-Centred Design (UCD) methodology was paramount for the interface user-friendliness, which was highlighted by both groups of participants. Such an approach is essential to achieve a product that meets end-users' needs and satisfaction in graphical user interface development (Gonçalves et al., 2017). Using UCD to create graphical user interfaces in the housing co-design is uncommon, and no relevant evidence could be found in the existing literature. Some co-design systems presented in the literature (e.g. ModRule (Lo et al., 2015) and HOPLA-Home Planner (Kwieciński & Słyk, 2023))

developed interface solutions for housing customisation led by inhabitants. However, there is no evidence of their development through close contact with potential users. These works involved testing their frameworks with different types of users. However, their authors tested them with architectural students, acting as designers and end-users, which did not reflect the characteristics of the target users, or they only conducted an interface evaluation with real end-users using a prototype in an advanced phase. Although both produced paper prototypes to test their architectural design methods, no evidence of end-user involvement in the interface design in the preliminary phases following an iterative process was found, unlike in a user-centred design approach.

The contributions of this thesis are outlined in two frameworks: Theoretical and Practical

THEORETICAL FRAMEWORK

The scientific relevance of this thesis lies in the definition of how a digital tool can support co-design processes in housing customisation. This research contributes to the advancement of knowledge by providing the requirements necessary for the co-design of houses through a digital tool. The innovation is based on the fact that the requirements of such a tool are extracted from direct contact with potential users. A user interface that incorporates features aligned with such user requirements can contribute to more effective and informed collaboration.

Another relevant aspect relates to how inhabitants and architects perceive the relevance of such a tool. Regarding inhabitants, the introduction of a user interface for housing co-design is seen as an enabling way to customise their houses in an active and informed manner. The ability to make their own choices while being supported with predefined options to choose from and warnings about feasibility and budget is perceived as empowering, while acknowledging technical expertise.

On the other hand, this thesis highlights architects' difficulty in revising their role of sole authors of design decisions and in allowing end-users to participate in decision-making. The professionals' opinions expressed during the interviews reveal a general architects' reluctance towards collaborative practices. Nevertheless, after engaging with the interface, architects demonstrated a degree of openness, acknowledging that the tool could embed their technical expertise to ensure the feasibility of proposed solutions. Additionally, they argued that the interface was restrictive, as it only allowed the selection of predefined options, and could be used effectively in specific contexts. On the other hand, architects perceived the tool as limiting their professional role, thereby reverting to a defensive position regarding the distribution of roles within the design process. From a theoretical perspective, this thesis underscores the importance of training and reskilling architects, as suggested in the literature, to embrace a new professional role.

PRACTICAL FRAMEWORK

The practical relevance of this thesis is the outcome's applicability to real-world scenarios. The proposed digital interface for the co-design of houses has significant potential for architecture. A user-friendly interface offers the opportunity for end-users to engage actively in the design process, enhancing participatory processes in collective housing. It has the potential to improve end-users' satisfaction and enhance participation in their houses' design process since it allows for the customisation of housing while still accommodating construction regulations and budget constraints, contributing to more effective and informed collaboration. This level of engagement facilitates the creation of designs tailored to meet the specific needs of inhabitants. By means of a digital co-design tool, architecture can respond to the users' diversity.

The tool can be meaningfully integrated into the overall architectural design process as a mediating instrument, between inhabitants and professionals, that structures asynchronous communication, supports informed decision-making, and bridges the gap between non-specialists and professional expertise. Inhabitants can thereby contribute from early design stages, when important decisions are made, defining house layouts that subsequently inform the work of other specialities. Its integration into the architectural process underscores the potential to reconfigure conventional design practices towards participatory and collaborative models, aligning with contemporary calls in the literature for a redefinition of the architect's role.

Despite being defined in the Portuguese context, this interface can be adapted to other geographical or architectural contexts. The design rules defined by the architects are set according to the local regulations and architectural language. Furthermore, besides cooperative housing, it also holds potential to be adaptable to other contexts where end users are known before the construction, such as in governmental initiatives that rehouse specific communities. Rehabilitation projects can also benefit from such a co-design tool by customising housing designs within a pre-established floorplan.

6.3.2 Limitations and future work

Despite the promising outcomes, this research also has some limitations. This section reflects on the research limitations and suggests future developments.

Firstly, although the tool is intended to be adaptable to any geographic context, there are limitations related to the type of project and cultural issues. Both the initial interviews and the iterative evaluation process were conducted exclusively with Portuguese participants. This may have influenced the requirements and shaped the interface development for this audience, potentially limiting its applicability to broader international contexts.

Another relevant aspect concerns limitations from the use of a simulated scenario using a prototype rather than fully implemented features that would have allowed participants to explore a

broader range of possibilities. Consequently, certain usability challenges encountered during testing may not have arisen in the context of a fully operational version. Moreover, the predefined scenario did not necessarily reflect the participants' aspirations and choices they would genuinely make, thereby hindering the accurate assessment of their satisfaction with the design outcome. Also, by having a script to follow, participants may have focused their attention on successfully performing the tasks instead of assessing the interface's full potential.

Another limitation of the research is that only part of the envisioned system features were developed. The research focused on the graphical interface intended for inhabitants' use, while the generative component, responsible for offering design options and providing feedback based on user input, remained undeveloped. Similarly, the interface intended for architects was not implemented. As a result, architects' evaluations of the tool may have been influenced by the absence of experimenting with the full system context.

Finally, while four iterations were conducted, encompassing requirement definition, evaluation, and refinement, the usability of the interface could be further enhanced through additional iterative cycles. For instance, improvements in the visibility of certain interface elements may benefit from additional refinement informed by user engagement.

One avenue for future research is the further development and evaluation of the proposed system with a more comprehensive and geographically varied user sample. Internationally expanding the participant pool would enrich the empirical foundation of the study and enable more robust conclusions regarding the system's applicability across different cultural and spatial contexts. Designing and testing the proposed interface with a broader cultural sample would require its localisation for other geographical contexts, including eliciting user requirements in those settings and adapting the interface to factors such as colour conventions, language, and wider cultural considerations. The use of the system in a different geographical context would also require the generative component to be supplied with architectural rules adapted to the environmental, regulatory and geographical conditions specific to that context.

Additionally, the full implementation of all intended functionalities is suggested. This includes the integration of the graphical interface with a generative design system, which would embed architectural expertise to support user decision-making. Another alternative would be using AI-based generative technology for the creation and editing of 2D floorplans and 3D geometries from prompt specifications.

Moreover, future work should encompass the development of a dedicated graphical user interface for architects, as well as a framework that enables them to define the design rules to feed the generative system.

Such developments can result in a fully operational tool that can be tested in real-world co-design contexts. By improving the proposed tool, a more comprehensive and collaborative design environment can be fostered, thereby effectively bridging professional expertise and user contributions within a digitally mediated co-design process. In turn, this could support the broader adoption of digital co-design methodologies within architectural practice and participatory frameworks for the development of customised housing solutions.

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Appendix

Appendix A: Interviews Protocol

(Portuguese Version)

QUESTIONÁRIO A PROFISSIONAIS

1 – Profissionais com experiência em processos participativos

1. Acha que o fato de um edifício (ou conjunto de edifícios) ser projetado para habitação em massa, dificulta a capacidade de desenhar de modo personalizado?
2. Acha que para uma habitação ser personalizada é essencial que o utilizador final participe no processo de projeto?
3. Como ocorreu a participação?
   a) Em que aspetos os habitantes participaram?
4. Qual considera ser a melhor forma de lidar com um grupo de pessoas num processo participativo?
5. Quais foram as dificuldades ou limitações no processo?
6. Sentiu que a comunidade tinha interesse em participar?
7. Quantas pessoas participaram? O grupo era variado (relativamente à idade, profissão, capacidade de perceção do projeto…)?
8. Acha que os habitantes devem "pôr mãos à obra", colaborando no desenho e não apenas na tomada de decisões?
   b) Como podem eles colaborar no desenho?
   c) Quais seriam os limites dessa colaboração?
9. O que foi apresentado aos participantes? Em que suporte?
10. O que os participantes fizeram?
11. Considera que foi um processo de co-design ou de participação?
12. Foi utilizado algum tipo de tecnologia digital? Qual?
13. De que forma as tecnologias digitais podem auxiliar estes processos?
14. De que formas as tecnologias influenciam a perceção do espaço por não profissionais?

15. De que forma as tecnologias podem envolver/ entusiasmar a comunidade?

16. De que forma as tecnologias podem balancear entre as limitações dos regulamentos de construção e a liberdade da comunidade desenhar?

17. Como pode um grupo de pessoas colaborar usando a mesma ferramenta digital (e em simultâneo)?

2 – Profissionais sem experiência em processos participativos

1. Acha que as habitações inseridas em edifícios ou bairros de habitação em massa devem ser personalizadas, isto é, ajustadas às necessidades individuais dos seus habitantes?

2. Acha que o fato de um edifício (ou conjunto de edifícios) ser projetado para habitação em massa, dificulta a capacidade de desenhar de modo personalizado?

3. Acha que para uma habitação ser personalizada é essencial que o utilizador final participe no processo de projeto?

   a. Em que moldes considera que esta participação pode ocorrer?

4. Quais considera ser as consequências da participação dos habitantes no projeto da sua casa?

5. Qual considera ser a melhor forma de lidar com um grupo de pessoas num processo participativo?

6. Quais são as dificuldades que causam a falta de processos participativos em arquitetura?

7. Considera que a comunidade tem interesse em participar?

8. Acha que os habitantes devem "pôr mãos à obra", colaborando no desenho e não apenas na tomada de decisões?

   a. Como podem eles colaborar no desenho?

   b. Quais seriam os limites dessa colaboração?

9. Que métodos são mais eficazes para conduzir um processo participativo?

10. De que forma as tecnologias digitais podem facilitar estes processos?

(English Version)

QUESTIONNAIRE FOR PROFESSIONALS

1 – Group A: Professionals with experience in participatory processes

1. Do you think that the fact that a building (or set of buildings) is designed for mass housing hinders the ability to design in a customised way?
2. Do you think that the end user's participation in the design process is essential for a house to be customised?
3. How did the participation occur?
    a. In what aspects did the community participate?
4. What is the best way to deal with a group of people in a participatory process?
5. What were the difficulties or limitations in the process?
6. Did you feel that the community was interested in participating?
7. How many people participated? Was the group diversified (in terms of age, profession, perception of the design…)?
8. Do you consider that the inhabitants should “put their hands on” the design, collaborating on it rather than just in decision-making?
    a. How can they collaborate in the design?
    b. What would be the limits of this collaboration?
9. What was presented to the participants? On what support?
10. What did the participants do?
11. Do you consider it was a process of co-design or participation?
12. Was any type of digital technologies used? What type of digital technology was used?
13. How can digital technologies assist these processes?
14. How do digital technologies influence non-designers' perception of space?
15. How can digital technologies engage the community?
16. How can digital tools balance the limitations of construction regulations and the freedom of the community to design?

17. How can a group of people collaborate simultaneously using the same digital tool?

2 – Group B: Professionals without experience in participatory processes

1. Do you think houses within mass housing projects should be customised, that is, adjusted to the individual needs of their inhabitants?
2. Do you think that the fact that a building (or set of buildings) is designed for mass housing hinders the ability to design in a customised way?
3. Do you think that the end user's participation in the design process is essential for a house to be customised?
    a. In what ways do you think this participation can occur?
4. What are the consequences of the inhabitants' participation in the design of their houses?
5. What is the best way to deal with a group of people in a participatory process?
6. What do you consider to be the difficulties that cause the few participatory processes in architecture?
7. Do you consider the community is interested in participating in participatory processes?
8. Do you consider that the inhabitants should “put their hands on” the design, collaborating on it rather than just on decision-making?
    a. How can they collaborate in the design?
    b. What would be the limits of this collaboration?
9. What are the most effective methods for conducting a participatory process?
10. How can digital technologies assist these processes?

(Original Portuguese Version)

QUESTIONÁRIO A COOPERATIVAS

1. Como funciona na associação/cooperativa o processo de construção de edifícios de habitação – quem são os interlocutores e quais são as fases?
2. Sobre os edifícios de habitação coletiva que construíram:
    a. Em que zonas geográficas têm trabalhado mais?
    b. Para que níveis económicos da população têm trabalhado mais?
    c. De que faixas etárias são os associados da cooperativa?
3. Nos edifícios de habitação que promovem, o projeto de arquitetura é realizado por um escritório de arquitetura por vocês contratado? É normal contratar várias vezes o mesmo escritório?
4. Houve participação dos habitantes/ cooperadores no processo de desenho das suas casas?
    a. Quem impulsionou a participação dos habitantes? (habitantes, cooperativa, arquiteto…)
    b. Em que momentos os habitantes intervieram?
    c. De que forma participaram? Como foi dinamizada a sessão de participação?
    d. Os habitantes mostraram-se motivados em participar? (senão, como é que foi feito?)
5. (Se não houve participação) Os habitantes expressaram a opinião de que gostariam de ter participado?
6. Qual era a diversidade do grupo de habitantes que participou nas sessões relativamente à idade, profissão, capacidade de perceção do projeto, ligação com tecnologias, etc?
7. Acha que os habitantes ficaram satisfeitos com o resultado?

(Translated English Version)

QUESTIONNAIRE FOR HOUSING COOPERATIVES

1. How does the process of building housing in the association/cooperative – who are the stakeholders, and what are the phases?
2. About the collective housing buildings the cooperative built:
    a. In which geographic areas have you worked the most?
    b. For which economic levels of the population have you worked the most?
    c. What age groups are the cooperative members from?
3. In the residential buildings you promote, is the architectural design carried out by an architectural office you hire? Is it normal to hire the same office several times?
4. Was there participation of the inhabitants/cooperators in the process of designing their houses?
    a. Who encouraged the participation of the inhabitants? (inhabitants, cooperative, architect…)
    b. When did the inhabitants step in?
    c. How did they participate? How was the participation session organised?
    d. Were the inhabitants motivated to participate? (If not, how was it done?)
5. (If there was no participation) Did the inhabitants express the opinion that they would have liked to have participated?
6. What was the diversity of the group of residents who participated in the sessions in terms of age, profession, ability to understand the project, relationship with technologies, etc?
7. Do you think the inhabitants were satisfied with the result?

(Original Portuguese Version)

QUESTIONÁRIO A HABITANTES

1 – Introdução – Criar empatia

1. Como se chama?
2. Que idade tem?
3. Qual é o seu nível de escolaridade?
4. Qual é a sua profissão?
5. O que gosta de fazer?
6. O que é mais importante para si em relação à sua nova casa (o que gostaria mais que a casa tivesse / O que mais gosta na sua casa)? Porquê?
7. Se pudesse mudar alguma coisa na sua casa, o que seria?
8. Como é a sua relação com as tecnologias digitais?
    a. Que tecnologias usa diariamente?
        i. Quais os dispositivos e para que atividades

2 – Perguntas exploratórias – Sobre o processo que passou

9. Porque procurou uma cooperativa para fazer a sua casa? (Motivação – O que queria?)
10. Quando foi o projeto?
11. Quem participou? (perguntar sobre outros intervenientes, ex: cooperativa, arquiteto…)
12. Sobre que partes do projeto deu a sua opinião ou ideias, e como se decidiram os espaços comuns (se aplicável)?
13. Como participou - o que fez exatamente e com que materiais?
14. O que lhe foi mostrado pelo arquiteto de modo a perceber o projeto?
15. Que dificuldades sentiu? Sentiu dificuldades em entender o que lhe foi mostrado?
16. Que diferenças houve entre a sua perceção inicial da casa, em projeto, e o resultado final construído?

3 – Conclusão – Sobre satisfação (Pains/Gains)

17. Ficou satisfeito com o resultado (do projeto) da sua casa? O resultado foi idêntico ao que esperava?

a. Acha que se (não) tivesse participado, o resultado seria o mesmo?

18. O que mudaria agora e porquê?

19. Qual foi o aspeto do processo que mais gostou?

20. O que gostaria que tivesse sido diferente no processo?

a. Na sua relação com o projetista

b. No número de vezes que falou com o responsável pelo projeto

c. Nos elementos com os quais trabalhou - o que gostaria de ter feito que não fez ou vice-versa (Desenhar, manipular objetos, falar, escrever, representar…- com objetos físicos ou digitais)

21. Gostaria que o projetista acompanhasse o processo integralmente ou preferia explorar sozinho (ou com família, amigos…) partes do projeto? Porquê?

22. Escolha que elementos gostaria que um sistema digital tivesse, para o ajudar a participar no projeto da sua casa. Ordene-os por prioridade.

a. Elementos de arquitetura

Elementos que gostaria de poder decidir		Prioridade
Forma da casa		
Quantidade e dimensão de cada tipo de divisão		
Layout da habitação inteira (automático)		
Layout de cada divisão (passo a passo)		
Organização do interior (posição e relação entre divisões)		
Limites e permeabilidades		
Materiais e acabamentos		

b. Tipo de interação

Elementos que gostaria de poder decidir		Prioridade
Drag and Drop		
Clicar em imagens/botões		
Desenhar		
Escolha tipo catálogo		
Sliders		
Preenchimento de campos		

c. Tipo de visualização

Elementos que gostaria de poder decidir		Prioridade
Planta/ desenhos esquemáticos		
3D esquemático		
Planta/ desenhos técnicos detalhados		
Planta/ desenhos animados		
Vistas interiores estática		
3D interativo/ walkthrough		

d. Dispositivos e interface

Elementos que gostaria de poder decidir		Prioridade
Computador (rato e teclado)		
Smartphone (touchscreen)		
Tablet (touchscreen)		
Mesa digital (multi-touchscreen)		
HMD (realidade virtual imersiva)		

(Translated English Version)

QUESTIONNAIRE FOR INHABITANTS

1 – Introduction – Creating empathy

1. What is your name?
2. How old are you?
3. What is your level of education?
4. What is your profession?
5. What do you like to do?
6. What is most important to you about your new home (what would you like the house to have / What do you like most about your home)? Why?
7. What would it be if you could change anything in your home?
8. How is your relationship with digital technologies?
    a. What technologies do you use daily?
        i. Which devices and for what activities

2 – Exploratory questions – About the process they went through

9. Why did you look for a cooperative to build your house? (Motivation – What did they want?)
10. When was the project?
11. Who was involved? (ask about other stakeholders, e.g., cooperative, architect…)
12. About which parts of the project did you give your opinion or ideas, and how were the common spaces decided (if applicable)?
13. How did you participate – what exactly did you do, and with what materials?
14. What was shown to you by the architect in order to understand the design?
15. What difficulties did you experience? Did you have difficulty understanding what was shown to you?
16. What differences were there between your initial perception of the house, as a design, and the final result that was built?

3 – Conclusion – About satisfaction (Pains/Gains)

17. Were you satisfied with your house's result (of the design)? Was the result identical to what you expected?

a. Do you think that if you had (not) participated, the result would have been the same?

18. What would you change now and why?

19. What was the aspect of the process you enjoyed the most?

20. What would you like to have been different in the process?

a. Regarding your relationship with the designer

b. Regarding the number of times you spoke to the person responsible for the project

c. Regarding the elements you worked with - what would you have liked to have done that you did not do or vice versa (Drawing, manipulating objects, talking, writing, representing... - with physical or digital objects)

21. Would you like the designer to follow the entire process, or would you prefer to explore parts of the project alone (or with family, friends...)? Why?

22. Decide which elements you would like a digital system to have to help you participate in the design of your house. Order them by priority.

a. Features

Elements they wish they could decide		Priority
House shape		
Rooms number and dimensions		
Automatic generation of the entire house's layout		
Step by step layout		
Interior layout arrangement		
Limits and permeabilities		
Finishing materials		

b. Type of interaction

Elements they wish they could decide		Priority
Drag and Drop		
Clicking on images or buttons		
To Draw		
Choosing from a catalogue		
Sliders		
Form filling		

c. Type of visualisation

Elements they wish they could decide		Priority
Schematic drawings		
Schematic three-dimensional (3D) model		
Detailed drawings		
Humanised floorplans		
Static interior views		
Interactive/walkthrough 3D model		

d. Devices

Elements they wish they could decide		Priority
Computer (mouse and keyboard)		
Smartphone (touchscreen)		
Tablet (touchscreen)		
Interactive digital table (multi-touchscreen)		
HMD (immersive Virtual Reality)		

Appendix B: Formative Evaluation Protocol

(Original Portuguese Version)

PROTOCOLO E EXPLICAÇÃO DA EXPERIÊNCIA

Este guião deve ser verbalizado pelo investigador aos participantes e poderá ser lido ou memorizado e dito, desde que a mesma informação chegue às pessoas que irão efetuar o teste.

"Antes de mais, quero agradecer a sua participação neste teste, a sua opinião é uma parte importante para o estudo que está a ser realizado. Irá participar na avaliação de uma ferramenta digital para o co-design de habitações, desenvolvida com base nos resultados das entrevistas feitas num estudo anterior.

Para contextualizar, estas entrevistas serviram para perceber como ocorrem os processos participativos e como uma ferramenta digital poderia ajudar os habitantes a participar no projeto das suas casas. Auxiliaram também a definição das partes do projeto sobre as quais os habitantes gostariam de tomar decisões, os dispositivos e os modos de interação e visualização com os quais se sentem mais confortáveis ao usar uma ferramenta digital para desenhar as suas casas.

O objetivo deste teste é perceber a sua opinião relativamente à ferramenta que lhe vai ser apresentada, nomeadamente em relação à facilidade de uso. Numa primeira fase, ser-lhe-á entregue um termo de consentimento, que deve ser lido e assinado se concordar com o conteúdo, para garantir que o teste é feito voluntariamente. Caso esteja de acordo, e depois de responder a um pequeno questionário preliminar, prosseguimos para a próxima fase onde lhe será pedido que realize algumas tarefas para que possa experimentar o protótipo e dar a sua opinião.

Solicito-lhe agora que leia o Termo de Consentimento, onde tem acesso à informação mais detalhada sobre objetivos e condições do estudo, e, caso concorde com tudo, assine e preencha o questionário preliminar."

[Entrega e assinatura do Termo de consentimento]

[Entrega e preenchimento do Questionário Preliminar]

Antes de serem fornecidas tarefas ao participante, o investigador deverá dar as seguintes instruções:

"Vou agora passar à explicação de como a experiência vai ocorrer: Este é o protótipo que irá ser avaliado. Vai ter a oportunidade de experimentá-lo através da realização de oito tarefas simples, que estão descritas num guião que lhe vou disponibilizar no início da experiência. São cinco ecrãs, que correspondem às cinco fases do projeto com as quais irá interagir: a definição de requisitos, organização dos espaços, ligações e passagens, pormenorização dos espaços e escolha de materiais. Em cada um é necessário fazer alguns passos para concretizar a tarefa.

Enquanto estiver a realizá-las, vai ser acompanhado por uma simulação da resposta do sistema às suas ações. Peço-lhe que preste atenção a todos os elementos do "ecrã" e às indicações que vão surgindo, porque eu não posso ajudar na realização das tarefas, uma vez que o que está a ser avaliado é a capacidade que o sistema tem de transmitir como se deve proceder. Reforço que em nenhum momento está a ser avaliado(a). O único alvo de avaliação neste teste é a ferramenta. Peço-lhe também que durante a realização das tarefas diga em voz alta o que está a pensar e quais as suas dificuldades e opiniões que surgem no momento.

Após a realização de cada tarefa, deve responder a um pequeno questionário que lhe será igualmente disponibilizado. Deve ser respondido logo após a realização de cada tarefa, porque é quando a informação ainda está fresca na memória. Se não conseguir completar uma tarefa, não se preocupe, passaremos à próxima. Quando terminar, ser-lhe-á pedido que responda a um pequeno questionário final de satisfação em relação à ferramenta em geral.

Caso tenha alguma dúvida, esteja à vontade para colocá-la. Quando estiver pronto, podemos iniciar a experiência".

[Entrega do Guião de tarefas]

[Entrega do Questionário SEQ]

[Realização das tarefas e resposta ao Questionário SEQ por parte do participamte]

[Entrega do Questionário SUS]

[Entrega do Questionário GUI]

“Diga por favor, os três aspetos que mais gostou”

[Anotar]

1-

2-

3-

“Diga por favor os três aspetos que menos gostou”

[Anotar]

1-

2-

3-

(Translated English Version)

PROTOCOL AND EXPERIENCE EXPLANATION

This script should be spoken by the researcher to participants. It may be read aloud or memorised and recited, as long as the same information is conveyed to those taking part in the test.

“First of all, I want to thank you for participating in this test. Your opinion is an important part of the study being conducted. You will participate in evaluating a digital tool for co-designing housing, based on the results of interviews conducted in a previous study.

To provide context, those interviews aimed to understand how participatory processes occur and how a digital tool could help residents take part in designing their houses. They also helped define which parts of the project residents would like to make decisions about, as well as the devices, interaction modes, and visualisation methods they feel most comfortable using when working with a digital tool to design their homes.

The goal of this test is to understand your opinion about the tool that will be presented to you, particularly regarding its ease of use. In the first phase, you’ll be given a consent form, which you should read and sign if you agree with its contents, to ensure the test is conducted voluntarily. If you agree, and after completing a short preliminary questionnaire, we’ll move on to the next phase, where you’ll be asked to perform a few tasks so you can try out the prototype and share your opinion.

I now ask you to read the Consent Form, which contains more detailed information about the study’s objectives and conditions. If you agree with everything, please sign it and fill out the preliminary questionnaire.

[Provision and signature of the Consent Form]

[Provision and completion of the Preliminary Questionnaire]

Before tasks are given to the participant, the researcher should provide the following instructions:

“I will now explain how the experience will unfold: This is the prototype that will be evaluated. You will have the opportunity to try it out by completing eight simple tasks, which are described in a script I will provide at the beginning of the experience. There are five screens, each corresponding to one of the five project phases you will interact with: requirements definition, space organisation, connections and pathways, space detailing, and material selection. Each screen involves a few steps to complete the task. While performing the tasks, you will be accompanied by a simulation of the system’s response to your actions. Please pay close attention to all elements on the screen and to the instructions that appear, because I will not be able to help you during the tasks, since what is being evaluated is the system’s ability to communicate how to proceed. I want to emphasise that you are not being evaluated at any point. The only subject of evaluation in this test is the interface. I also ask that, while performing the tasks, you speak aloud about what you are thinking, any difficulties you encounter, and any opinions that arise in the moment.

After completing each task, you will be asked to fill out a short questionnaire, which should be completed immediately after each task while the information is still fresh in your memory. If you are unable to complete a task, don’t worry, we will move on to the next one. Once you have finished, you will be asked to complete a short final satisfaction questionnaire about the tool overall.

If you have any questions, feel free to ask. When you are ready, we can begin the experience.”

[Provision of the Task Script]

[Provision of SEQ Questionnaire]

[Execution of tasks and completion of the SEQ Questionnaire by the participant]

[Provision and filling of the SUS Questionnaire]

[Provision and filling of the GUI Questionnaire]

“Please identify the three aspects of the tool you appreciated most.”

[Record responses]

1.

2.

3.

“Please identify the three aspects of the tool you appreciated least.”

[Record responses]

1.

2.

3.

(Original Portuguese Version)

QUESTIONÁRIO PRELIMINAR

Número de participante:

Idade

☐ 25 – 30
☐ 31 – 35
☐ 36 – 40
☐ 41 – 45

Género

☐ Masculino
☐ Feminino
☐ Outro (Por favor, especifique) _____

Como avalia a sua relação com as tecnologias digitais?

☐ Muito má
☐ Insuficiente
☐ Razoável
☐ Boa
☐ Muito Boa

Alguma vez teve contato com projetos de arquitetura?

☐ Sim
☐ Não

Neste momento sinto-me … (assinalar as que se aplicam)

☐ Motivado(a)
☐ Apreensivo(a)
☐ Outro (Por favor especifique) _____

Obrigado pela sua participação!

(Translated English Version)

PRELIMINARY QUESTIONNAIRE

Participant Number:

Age

☐ 25 – 30
☐ 31 – 35
☐ 36 – 40
☐ 41 – 45

Gender

☐ Male
☐ Female
☐ Other (Please, specify) _____

How do you evaluate your relationship with digital technologies?

☐ Very bad
☐ Insufficient
☐Reasonable
☐ Good
☐ Very Good

Have you ever had contact with architectural projects?

☐ Yes
☐ No

At this moment I feel… (check those that apply)

☐ Motivated
☐ Apprehensive
☐ Other (Please, specify) _____

Thank you for your participation!

(Original Portuguese Version)

GUIÃO DE TAREFAS

Tarefas a serem realizadas pelo participante:

- **Tarefa 1:** Imagine que vai escolher as divisões que pretende que a sua casa tenha e, ao fazê-lo, quer adicionar uma cozinha. Adicione uma cozinha para 1 pessoa e, em seguida, escolha o tamanho da divisão.

- **Tarefa 2:** Imagine que já adicionou várias divisões e agora quer adicionar um escritório, mas não está na lista de opções para adicionar. Adicione uma divisão personalizada e dê-lhe o nome "escritório". Siga para a próxima fase.

- **Tarefa 3:** Após receber as opções de disposição da habitação, imagine que a opção que mais gostou foi a opção 3, mas ainda assim gostava de alterar a localização do quarto e da suíte. Escolha a opção 3 e personalize trocando a posição do quarto com a posição da suíte.

- **Tarefa 4:** Imagine que não gostou da passagem entre a sala e o corredor, e quer eliminá-la. Edite as passagens da casa e, em seguida, elimine a passagem entre a sala e o corredor.

- **Tarefa 5:** Imagine que pretende juntar numa única divisão a sala com a cozinha. Adicione uma abertura total entre a sala e a cozinha para ligar estes espaços. Prossiga para a pormenorização.

- **Tarefa 6:** Imagine que não gostou do tamanho da abertura que foi criada por defeito e quer aumentá-la. Troque a passagem "S" por uma passagem "M".

- **Tarefa 7:** Pormenorize as divisões. Imagine que pretende ter uma cozinha em "U". Troque o formato da cozinha.

- **Tarefa 8:** Escolha o material para o chão da sala. Imagine que gostou mais do soalho de madeira.

(Translated English Version)

TASKS SCRIPT

Tasks to be completed by the participant:

- **Task 1:** Imagine you are selecting the rooms you would like your house to have, and in doing so, you wish to add a kitchen. Add a kitchen suitable for one person, and then choose the size of the room.

- **Task 2:** Imagine you have already added several rooms and now want to include a study, but it is not listed among the available options. Add a custom room and name it "study". Proceed to the next phase.

- **Task 3:** After receiving the layout options for the house, imagine that your favourite is option 3, but you would still like to change the location of the bedroom and the suite. Select option 3 and customise it by swapping the position of the bedroom with the suite.

- **Task 4:** Imagine you do not like the passage between the living room and the hallway and want to remove it. Edit the house's passages and then delete the one between the living room and the hallway.

- **Task 5:** Imagine you want to combine the living room and kitchen into a single space. Add a full opening between the living room and the kitchen to connect these areas. Continue to the detailing phase.

- **Task 6:** Imagine you are not happy with the default size of the opening that was created and want to enlarge it. Replace the "S" opening with an "M" opening.

- **Task 7:** Add details to the rooms. Imagine you would like a U-shaped kitchen. Change the kitchen layout accordingly.

- **Task 8:** Choose the flooring material for the living room. Imagine you prefer a wooden floor.

(Original Portuguese Version)

QUESTIONÁRIO *SINGLE EASE QUESTION (SEQ)*

Número de participante:

Por favor, responda a cada pergunta após a realização de cada tarefa.

Tarefa 1

De uma forma geral, quão fácil ou difícil foi realizar esta tarefa?

Muito difícil Muito fácil

1	2	3	4	5	6	7

Tarefa 2

De uma forma geral, quão fácil ou difícil foi realizar esta tarefa?

Muito difícil Muito fácil

1	2	3	4	5	6	7

Tarefa 3

De uma forma geral, quão fácil ou difícil foi realizar esta tarefa?

Muito difícil Muito fácil

1	2	3	4	5	6	7

Tarefa 4

De uma forma geral, quão fácil ou difícil foi realizar esta tarefa?

Muito difícil Muito fácil

1	2	3	4	5	6	7

Tarefa 5

De uma forma geral, quão fácil ou difícil foi realizar esta tarefa?

Muito difícil Muito fácil

1	2	3	4	5	6	7

Tarefa 6

De uma forma geral, quão fácil ou difícil foi realizar esta tarefa?

Muito difícil Muito fácil

1	2	3	4	5	6	7

Tarefa 7

De uma forma geral, quão fácil ou difícil foi realizar esta tarefa?

Muito difícil Muito fácil

1	2	3	4	5	6	7

Tarefa 8

De uma forma geral, quão fácil ou difícil foi realizar esta tarefa?

Muito difícil Muito fácil

1	2	3	4	5	6	7

Obrigado pela sua participação!

(Translated English Version)

***SINGLE EASE QUESTION* (SEQ) QUESTIONNAIRE**

Participant number:

Please answer each question after completing each task.

Task 1

Overall, how easy or difficult was it to accomplish this task?

Very difficult Very easy

1	2	3	4	5	6	7

Task 2

Overall, how easy or difficult was it to accomplish this task?

Very difficult Very easy

1	2	3	4	5	6	7

Task 3

Overall, how easy or difficult was it to accomplish this task?

Very difficult Very easy

1	2	3	4	5	6	7

Task 4

Overall, how easy or difficult was it to accomplish this task?

Very difficult Very easy

1	2	3	4	5	6	7

Task 5

Overall, how easy or difficult was it to accomplish this task?

Very difficult Very easy

1	2	3	4	5	6	7

Task 6

Overall, how easy or difficult was it to accomplish this task?

Very difficult Very easy

1	2	3	4	5	6	7

Task 7

Overall, how easy or difficult was it to accomplish this task?

Very difficult Very easy

1	2	3	4	5	6	7

Task 8

Overall, how easy or difficult was it to accomplish this task?

Very difficult Very easy

1	2	3	4	5	6	7

Thank you for your participation!

(Original Portuguese Version)

QUESTIONÁRIO *SYSTEM USABILITY SCALE (SUS)*

Número de participante:

Para cada uma das afirmações abaixo, selecione a caixa (apenas uma por linha) que melhor descreve a sua opinião relativamente à ferramenta que acabou de experimentar:

	Discordo totalmente				Concordo totalmente
1- Eu acho que gostaria de usar este sistema com frequência					
	1	2	3	4	5
2- Eu achei este sistema desnecessariamente complexo					
	1	2	3	4	5
3- Eu achei o sistema fácil de usar					
	1	2	3	4	5
4- Eu acho que precisaria de suporte de um técnico para conseguir usar o sistema					
	1	2	3	4	5
5- Eu achei que as várias funções do sistema estão bem integradas					
	1	2	3	4	5
6- Eu achei que o sistema apresenta muitas inconsistências					
	1	2	3	4	5
7- Eu imagino que as pessoas aprenderiam a usar este sistema rapidamente					
	1	2	3	4	5
8- Eu achei que o sistema era complicado de usar					
	1	2	3	4	5
9- Eu senti-me muito confiante a utilizar o sistema					
	1	2	3	4	5
10- Eu precisei aprender muitas coisas antes de conseguir utilizar o sistema					
	1	2	3	4	5

Obrigado pela sua participação!

(Translated English Version)

***SYSTEM USABILITY SCALE (SUS)* QUESTIONNAIRE**

Participant number:

For each of the statements below, select the box (only one per line) that best describes your opinion about the tool you just tried:

	Totally disagree				Totally Agree
1- I think that I would like to use this system frequently					
	1	2	3	4	5
2- I found the system unnecessarily complex					
	1	2	3	4	5
3- I thought the system was easy to use					
	1	2	3	4	5
4- I think that I would need the support of a technical person to be able to use this system					
	1	2	3	4	5
5- I found the various functions in this system were well integrated					
	1	2	3	4	5
6- I thought there was too much inconsistency in this system					
	1	2	3	4	5
7- I would imagine that most people would learn to use this system very quickly					
	1	2	3	4	5
8- I found the system very cumbersome to use					
	1	2	3	4	5
9- I felt very confident using the system					
	1	2	3	4	5
10- I needed to learn a lot of things before I could get going with this system					
	1	2	3	4	5

Thank you for your participation!

(Original Portuguese Version)

QUESTIONÁRIO GRAPHICAL USER INTERFACE (GUI)

Número de participante:

Para cada uma das afirmações abaixo, selecione a caixa (apenas uma por linha) que melhor descreve a sua opinião relativamente à ferramenta que acabou de experimentar:

	Discordo totalmente				Concordo totalmente
1- Eu entendi os nomes das fases do projeto.					
	1	2	3	4	5
2- Não é fácil navegar pelos menus.					
	1	2	3	4	5
3- Eu entendi as opções e indicações do menu.					
	1	2	3	4	5
4- Os ícones e botões do menu não indicam claramente a sua função					
	1	2	3	4	5
5- Os gráficos e diagramas são fáceis de ler e entender					
	1	2	3	4	5
6- O design gráfico dos ecrãs não está bem desenhado					
	1	2	3	4	5
7- As informações estão bem organizadas nos ecrãs					
	1	2	3	4	5
8- Não é fácil aceder às informações de que preciso					
	1	2	3	4	5
9- O tamanho dos botões e das palavras ou frases é adequado					
	1	2	3	4	5

Obrigado pela sua participação!

(Translated English Version)

GRAPHICAL USER INTERFACE (GUI) QUESTIONNAIRE

Participant number:

For each of the statements below, select the box (only one per line) that best describes your opinion about the tool you just tried:

	Totally disagree				Totally Agree
1- I understood the names of the design phases					
	1	2	3	4	5
2- It's not easy to navigate through the menus					
	1	2	3	4	5
3- I understood the menu options and instructions.					
	1	2	3	4	5
4- Menu icons and buttons do not clearly indicate their function					
	1	2	3	4	5
5- Graphics and diagrams are easy to read and understand					
	1	2	3	4	5
6- The screen graphical design is not well designed					
	1	2	3	4	5
7- The information is well organized on the screens					
	1	2	3	4	5
8- It is not easy to access the information I need					
	1	2	3	4	5
9- The size of the buttons and words or statements is appropriate					
	1	2	3	4	5

Thank you for your participation!

(Original Portuguese Version)

GRELHA DE REGISTO DE REALIZAÇÃO DE TAREFAS

Número de participante:

Tarefa 1

Passos	Realizado	Não realizado	Tentativas*	Tempo
Clicar no botão "cozinha"				
Clicar no botão de 1 pessoa				
Arrastar a opção S para a área de escolhas				
Notas: (comentários do participante durante a realização da tarefa, comportamentos, etc)				

*Assinalar o número de ações realizadas até realizar a ação correta. Se o participante não conseguir realizar a tarefa após três tentativas, registar como não concluída, e passar à seguinte

Tarefa 2

(O computador humano mostra uma simulação com algumas divisões já escolhidas)

Passos	Realizado	Não realizado	Tentativas*	Tempo
Deslizar barra de deslizamento para procurar a opção "personalizar"				
Clicar em "personalizar" e escrever "escritório"				
Clicar em "organização" no canto inferior direito, para passar à próxima fase				
Notas: (comentários do participante durante a realização da tarefa, comportamentos, etc)				

*Assinalar o número de ações realizadas até realizar a ação correta. Se o participante não conseguir realizar a tarefa após três tentativas, registar como não concluída, e passar à seguinte

Tarefa 3

Passos	Realizado	Não realizado	Tentativas*	Tempo
Arrastar a “opção 3” para a área de interação				
Clicar em “personalizar”				
Arrastar a suíte para o lugar do quarto individual ou vice-versa				
(surge um aviso)				
Clicar em “aceitar”				
Notas: (comentários do participante durante a realização da tarefa, comportamentos, etc)				

*Assinalar o número de ações realizadas até realizar a ação correta. Se o participante não conseguir realizar a tarefa após três tentativas, registar como não concluída, e passar à seguinte

Tarefa 4

Passos	Realizado	Não realizado	Tentativas*	Tempo
Clicar no botão "ligações e passagens" no canto inferior direito, para passar à próxima fase				
Clicar em “editar passagens”				
Clicar na passagem entre o corredor e a sala, onde vai surgir a opção para eliminar				
Clicar na cruz para eliminar a passagem				
Notas: (comentários do participante durante a realização da tarefa, comportamentos, etc)				

*Assinalar o número de ações realizadas até realizar a ação correta. Se o participante não conseguir realizar a tarefa após três tentativas, registar como não concluída, e passar à seguinte

Tarefa 5

Passos	Realizado	Não realizado	Tentativas*	Tempo
Clicar na opção "total"				
Clicar na parede entre a sala e a cozinha, onde vai surgir a opção de eliminar				
Clicar na cruz para eliminar a passagem				
Clicar no botão "pormenorização" no canto inferior direito para passar à próxima fase				
(surge um aviso)				
Clicar em “aceitar”				
Notas: (comentários do participante durante a realização da tarefa, comportamentos, etc)				

*Assinalar o número de ações realizadas até realizar a ação correta. Se o participante não conseguir realizar a tarefa após três tentativas, registar como não concluída, e passar à seguinte

Tarefa 6

Passos	Realizado	Não realizado	Tentativas*	Tempo
Arrastar a opção "M" para o lugar da passagem que foi inserida por defeito (para substituí-la)				
Notas: (comentários do participante durante a realização da tarefa, comportamentos, etc)				

*Assinalar o número de ações realizadas até realizar a ação correta. Se o participante não conseguir realizar a tarefa após três tentativas, registar como não concluída, e passar à seguinte

Tarefa 7

Passos	Realizado	Não realizado	Tentativas*	Tempo
Clicar no botão "pormenorização" no canto inferior direito				
Clicar em cima da cozinha para selecioná-la				
Arrastar a opção de cozinha em U, para subtituí-la				
Notas: (comentários do participante durante a realização da tarefa, comportamentos, etc)				

*Assinalar o número de ações realizadas até realizar a ação correta. Se o participante não conseguir realizar a tarefa após três tentativas, registar como não concluída, e passar à seguinte

Tarefa 8

Passos	Realizado	Não realizado	Tentativas*	Tempo
Clicar em "materiais" para passar à próxima fase				
Clicar no botão “chão”				
Arrastar a ”soalho de madeira” para o chão da sala na planta				
Notas: (comentários do participante durante a realização da tarefa, comportamentos, etc)				

*Assinalar o número de ações realizadas até realizar a ação correta. Se o participante não conseguir realizar a tarefa após três tentativas, registar como não concluída, e passar à seguinte

(Translated English Version)

TASK COMPLETION RECORD GRID

Participant number:

Task 1

Steps	Completed	Not Completed	Tentatives*	Time
Click on the “kitchen” button				
Click on the 1 person button				
Drag the S option to the choices area				
Observations: Participant's comments during task execution, behaviours, etc.				

*Record the number of actions taken until the correct action is completed. If the participant is unable to complete the step within three attempts, mark it as incomplete and proceed to the next one

Task 2

(The human computer shows a simulation with some divisions already chosen)

Steps	Completed	Not Completed	Tentatives*	Time
Swipe the slider to find the “customise” option				
Click on “customise” and write “office”				
Click on “organisation” in the bottom right corner to move on to the next phase				
Observations: Participant's comments during task execution, behaviours, etc.				

*Record the number of actions taken until the correct action is completed. If the participant is unable to complete the step within three attempts, mark it as incomplete and proceed to the next one

Task 3

Steps	Completed	Not Completed	Tentatives*	Time
Drag “option 3” to the interaction area				
Click on “customise”				
Drag the suite to the single room's place or vice versa				
(a warning appears)				
Click “accept”				
Observations: Participant's comments during task execution, behaviours, etc.				

*Record the number of actions taken until the correct action is completed. If the participant is unable to complete the step within three attempts, mark it as incomplete and proceed to the next one

Task 4

Steps	Completed	Not Completed	Tentatives*	Time
Click on the "connections and passages" button in the lower right corner to move to the next phase				
Click on “edit connections”				
Click on the passage between the hallway and the room, where the option to delete will appear				
Click on the “X” button to delete the passage				
Observations: Participant's comments during task execution, behaviours, etc.				

*Record the number of actions taken until the correct action is completed. If the participant is unable to complete the step within three attempts, mark it as incomplete and proceed to the next one

Task 5

Steps	Completed	Not Completed	Tentatives*	Time
Click on the "total" option				
Click on the wall between the living room and the kitchen, where the option to delete will appear				
Click on the “X” button to delete the passage				
Click on the "detail" button in the bottom right corner to move to the next phase				
(a warning appears)				
Click “accept”				
Observations: Participant's comments during task execution, behaviours, etc.				

*Record the number of actions taken until the correct action is completed. If the participant is unable to complete the step within three attempts, mark it as incomplete and proceed to the next one

Task 6

Steps	Completed	Not Completed	Tentatives*	Time
Drag the "M" option to the place of the passage that was inserted by default (to replace it)				
Observations: Participant's comments during task execution, behaviours, etc.				

*Record the number of actions taken until the correct action is completed. If the participant is unable to complete the step within three attempts, mark it as incomplete and proceed to the next one

Task 7

Steps	Completed	Not Completed	Tentatives*	Time
Click on the "detail" button in the bottom right corner				
Click on the kitchen to select it				
Drag the U-shaped kitchen option to replace it				
Observations: Participant's comments during task execution, behaviours, etc.				

*Record the number of actions taken until the correct action is completed. If the participant is unable to complete the step within three attempts, mark it as incomplete and proceed to the next one

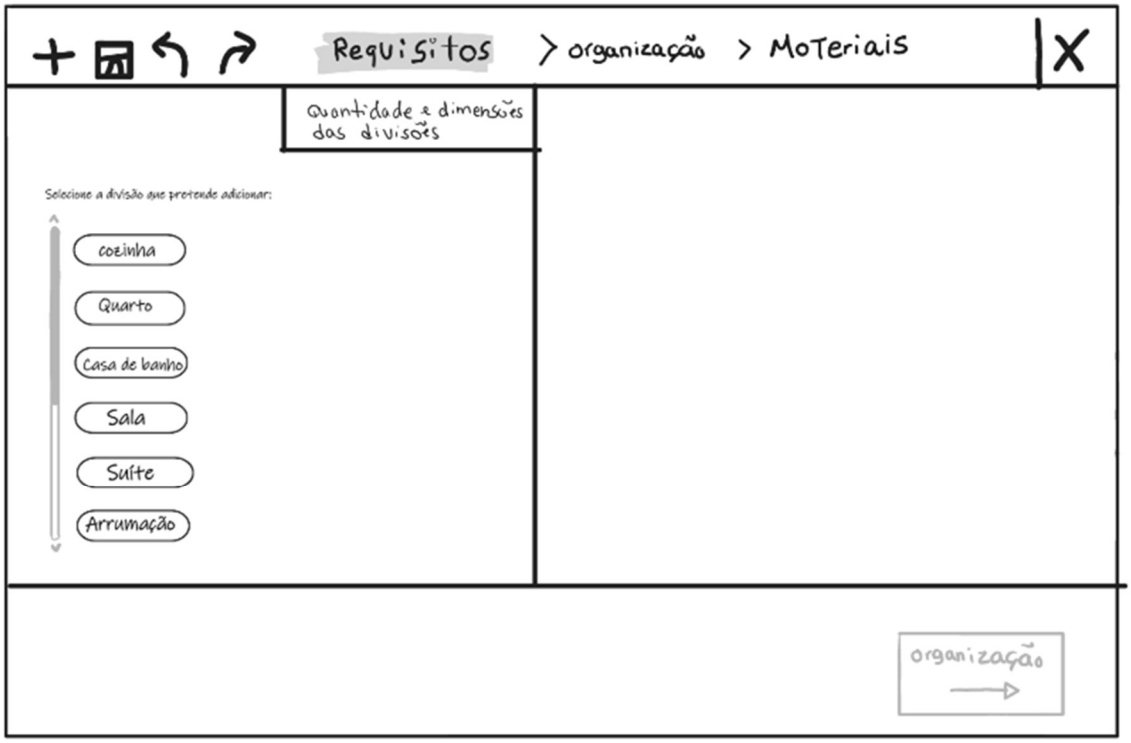
Task 8

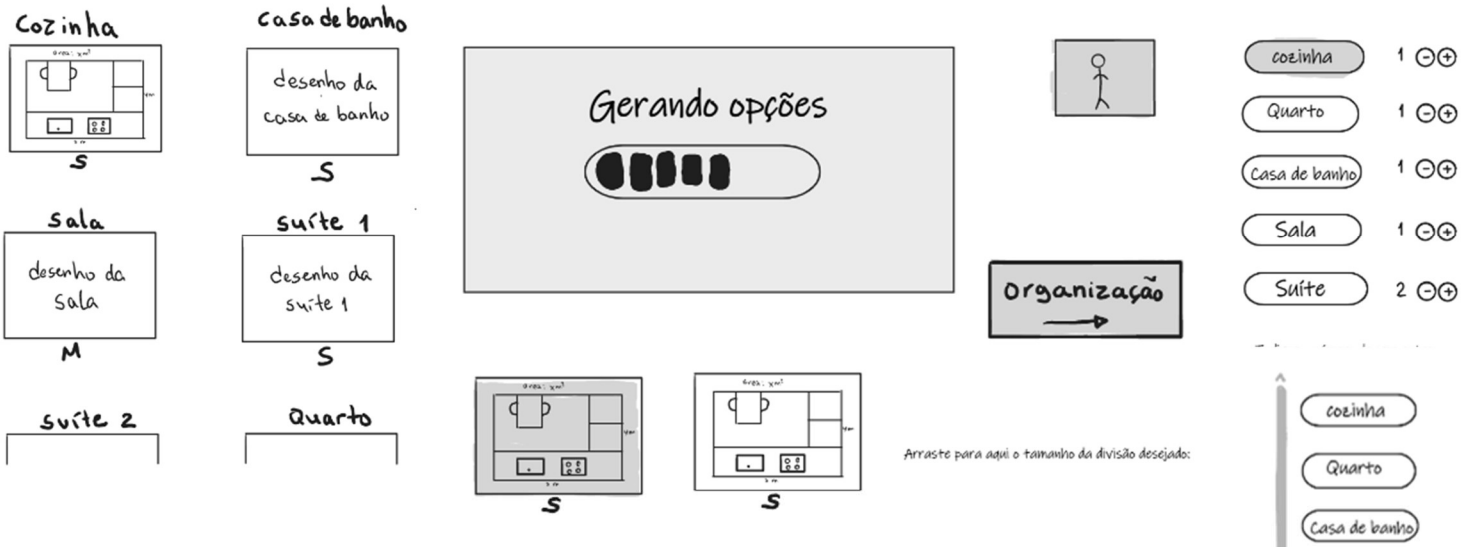
Steps	Completed	Not Completed	Tentatives*	Time
Click on "materials" to move to the next stage				
Click on the “floor” button				
Drag the "wood floor" to the living room floor in the floorplan				
Observations: Participant's comments during task execution, behaviours, etc.				

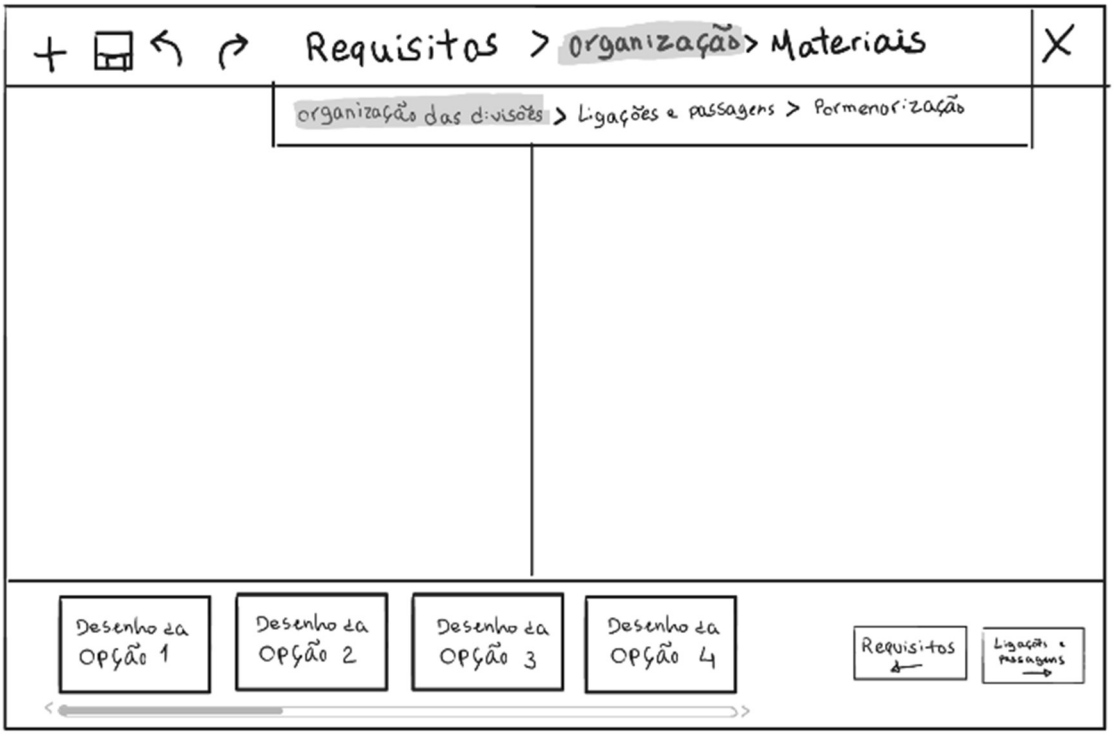
*Record the number of actions taken until the correct action is completed. If the participant is unable to complete the step within three attempts, mark it as incomplete and proceed to the next on

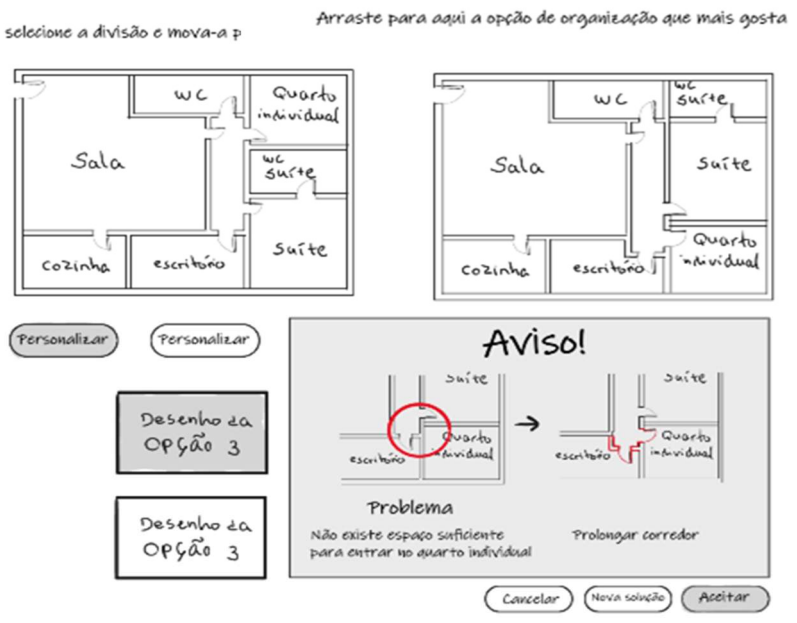
iscte INSTITUTO UNIVERSITÁRIO DE LISBOA
istar_iscte
fct Fundação para a Ciência e a Tecnologia

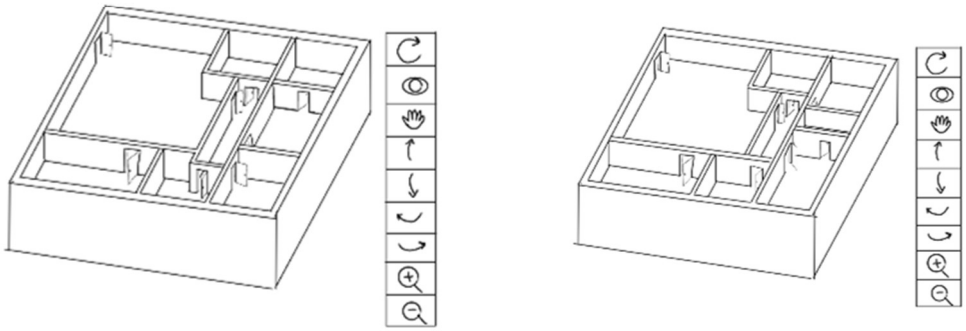
MATERIAL USADO PARA O PROTÓTIPO EM PAPEL

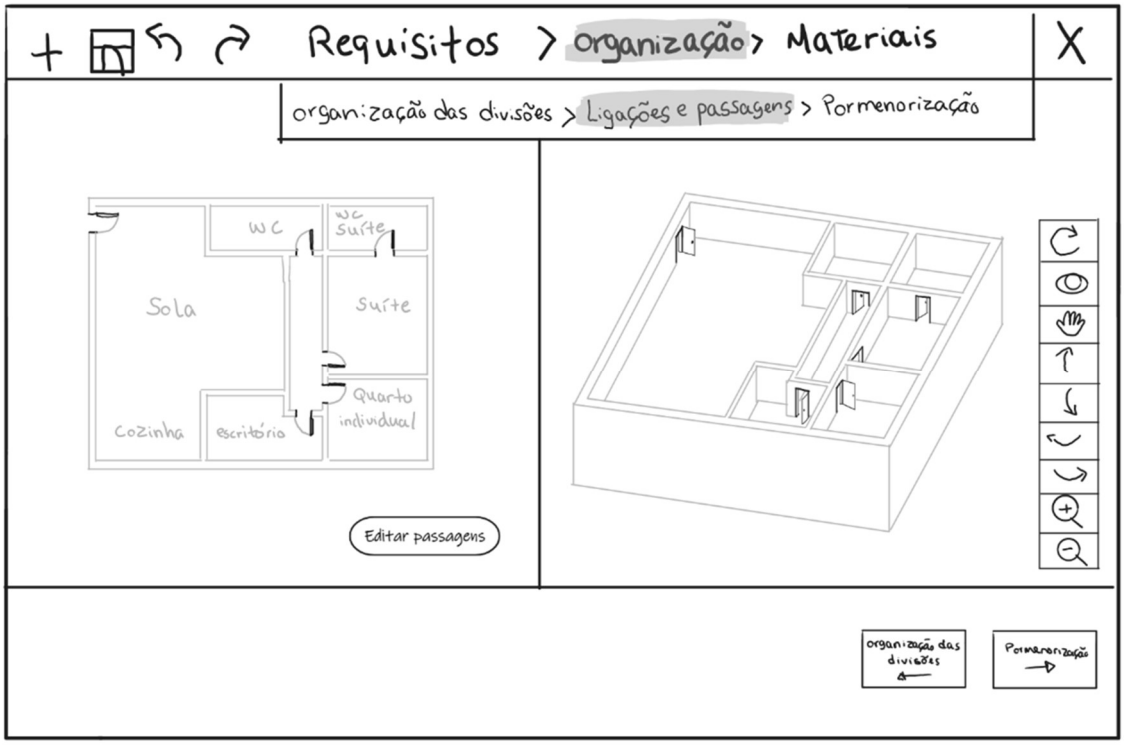


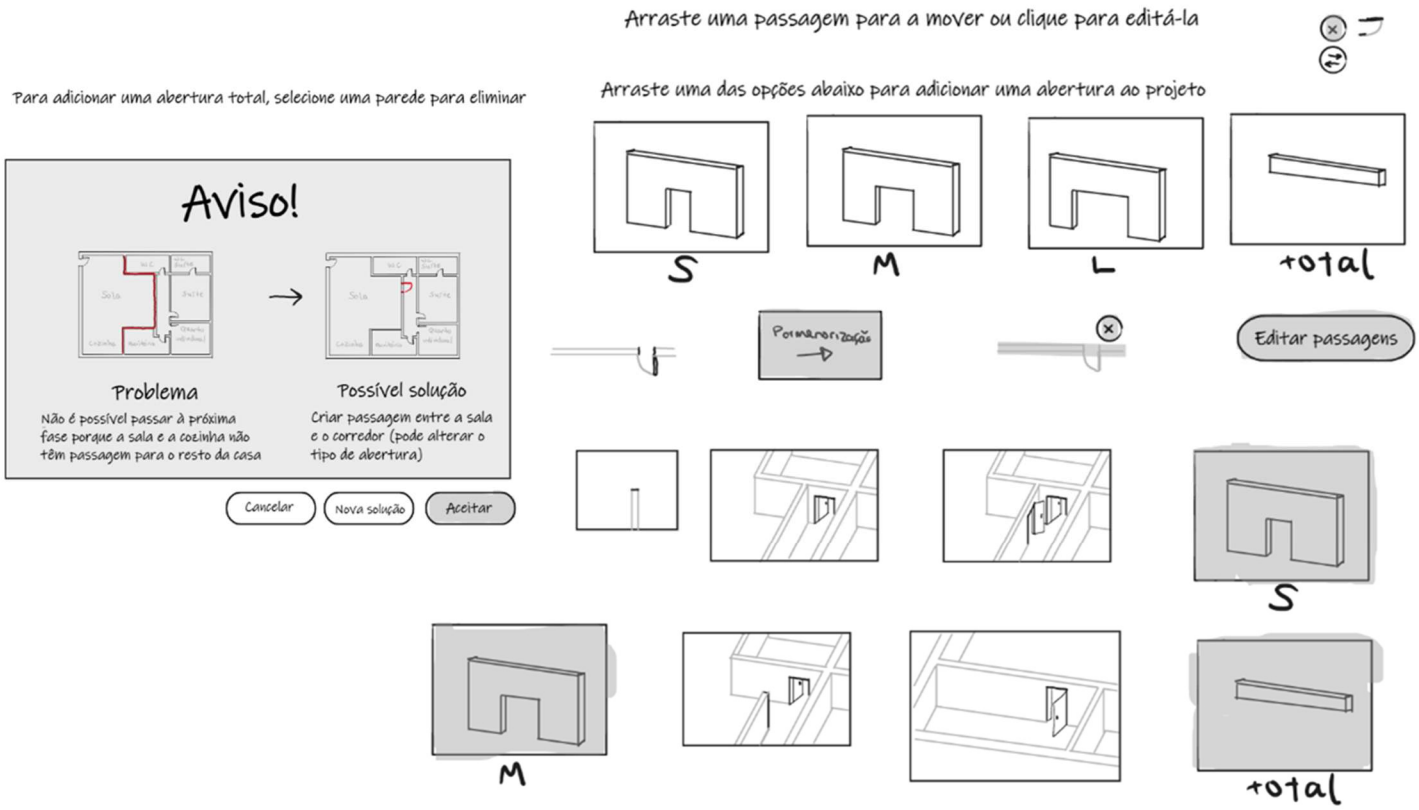


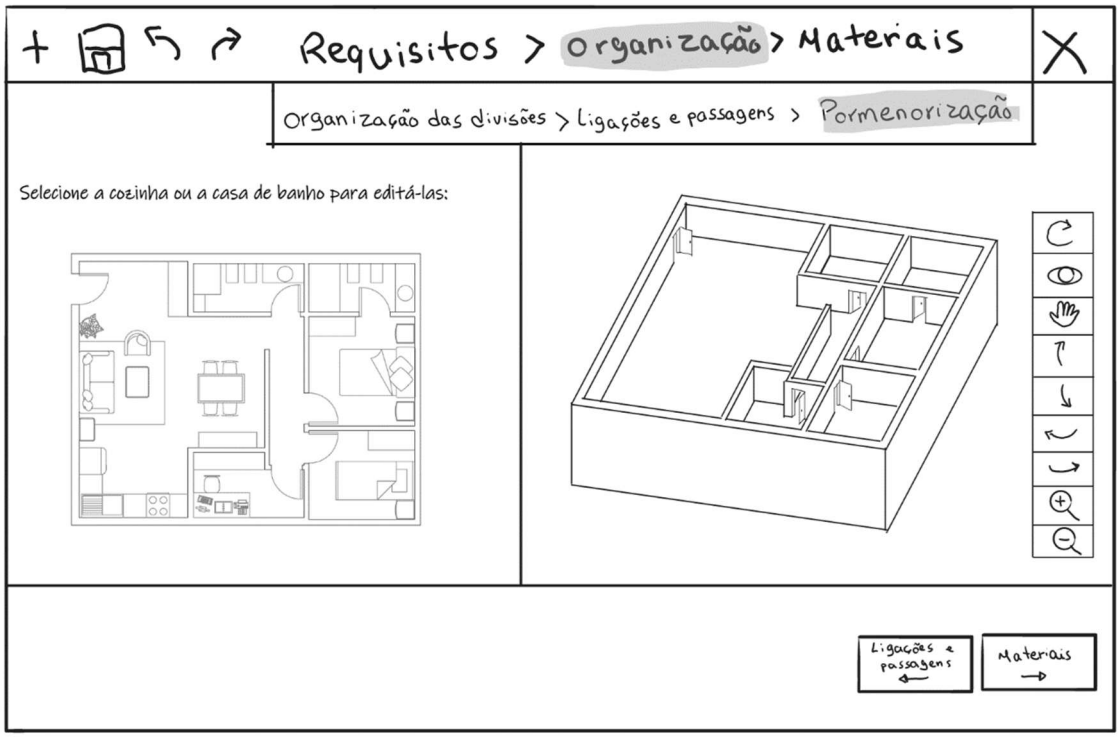

Requisitos > organização > Materiais
organização das divisões > Ligações e passagens > Pormenorização
Desenho da Opção 1
Desenho da Opção 2
Desenho da Opção 3
Desenho da Opção 4
Requisitos
Ligações e passagens

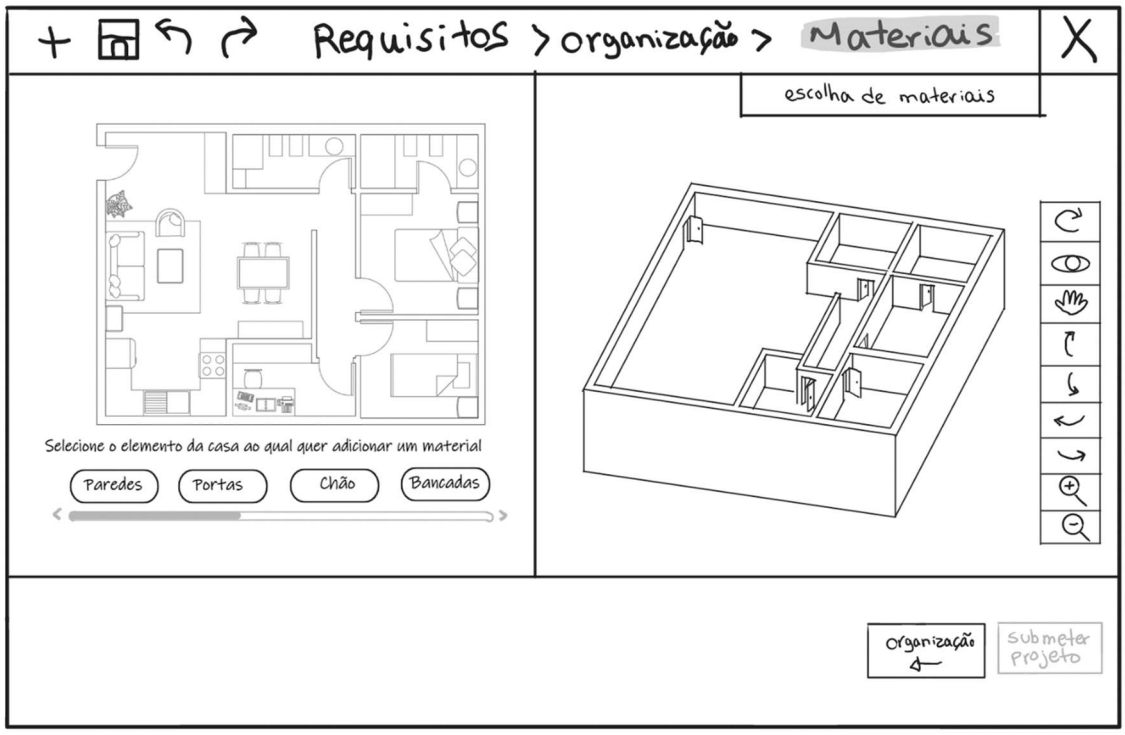

seleccione a divisão e mova-a p
Arraste para aqui a opção de organização que mais gosta
wc
Quarto individual
Sala
wc suíte
suíte
cozinha
escritório
Personalizar
Personalizar
Desenho da Opção 3
Desenho da Opção 3
Aviso!
Problema
Não existe espaço suficiente para entrar no quarto individual
Prolongar corredor
Cancelar
Nova solução
Aceitar

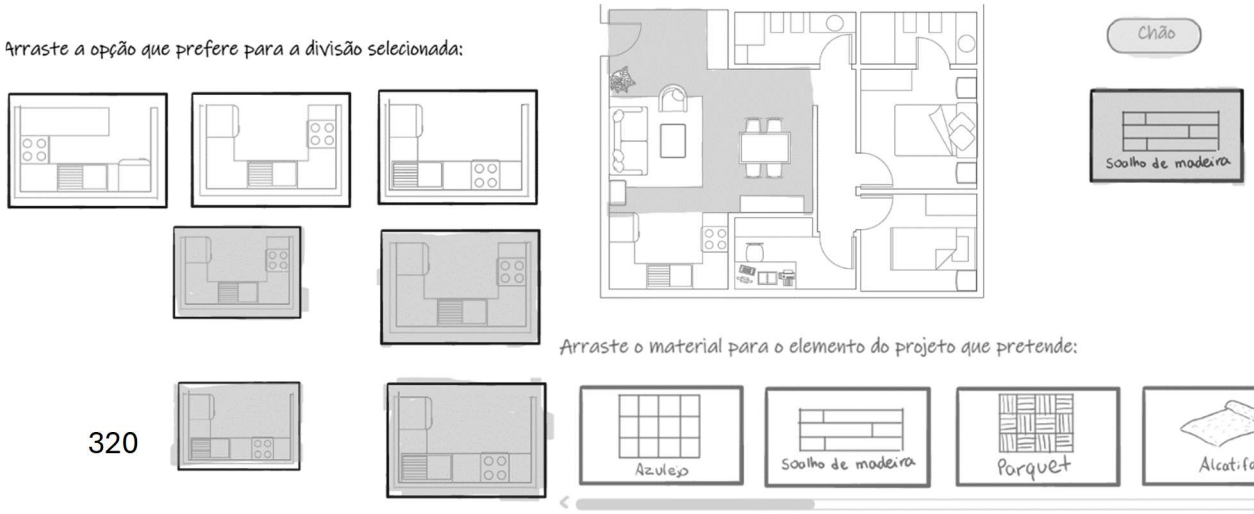



Requisitos > organização > Materiais
organização das divisões > Ligações e passagens > Pormenorização
WC
Suíte
Sala
Suíte
Quarto individual
Cozinha
escritório
Editar passagens
organização das divisões
Pormenorização


Arraste uma passagem para a mover ou clique para editá-la
Para adicionar uma abertura total, selecione uma parede para eliminar
Arraste uma das opções abaixo para adicionar uma abertura ao projeto
Aviso!
Problema
Não é possível passar à próxima fase porque a sala e a cozinha não têm passagem para o resto da casa
Possível solução
Criar passagem entre a sala e o corredor (pode alterar o tipo de abertura)
Cancelar
Nova solução
Aceitar
S
M
L
+otal
Pormenorização
Editar passagens
S
M
+otal


Requisitos > Organização > Materiais
Organização das divisões > Ligações e passagens > Pormenorização
Selecione a cozinha ou a casa de banho para editá-las:
Ligações e passagens
Materiais


Requisitos > organização > Materiais
escolha de materiais
Selecione o elemento da casa ao qual quer adicionar um material
Paredes
Portas
Chão
Bancadas
Organização
Submeter Projeto


Arraste a opção que prefere para a divisão selecionada:
Chão
Soalho de madeira
Arraste o material para o elemento do projeto que pretende:
Azulejo
Soalho de madeira
Parquet
Alcatifa

Appendix C: Heuristic Evaluation: a detailed description of usability issues identified by UX/UI expert

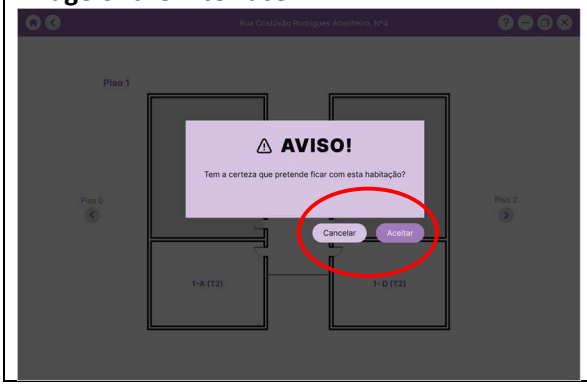
This appendix presents a description and consolidation of all the usability issues identified by the interface design experts, namely in User Experience (UX) and User Interface (UI). The description includes the identification of the issue, the Nielsen's heuristic violated, a description of how the issue violates the heuristic, a proposal for a solution, the level of severity attributed by the expert, and a screenshot of the interface showing the problem. Some issues were identified by more than one expert. In such cases, a consolidation was made by rewriting the description according to the comments of both experts, and the severity level was consolidated by the most severe level attributed. Table 1 refers to the list of issues identified, organised by severity level (left) and by priority (right), which was defined according to their frequency and level of severity. The description of each issue is given below.

Table 1 Organisation of the usability issues (left) by severity, (right) by priority

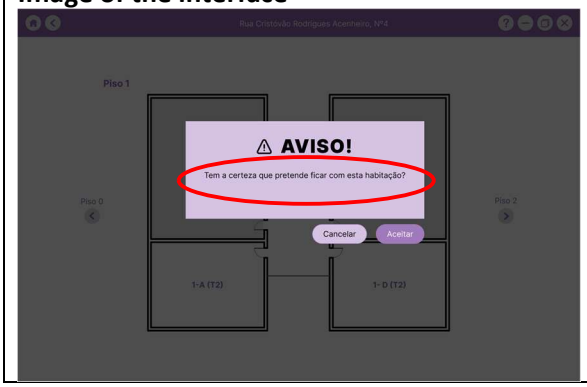
Issues organised by Severity	Issues organised by Priority
3	**P1- More frequent and severe**
Warnings	(3x) Library options' caption
Irreversible action information	(2x) Warnings
Undo/Redo	(2x) Order of hiding walls in the 3D view
"Customise" button	(2x) Order of associating the material with the element
Accept/cancel new solution	(2x) Drag the material
3D model menu options	**P2- Severe non-frequent**
Order of hiding walls in the 3D view	Undo/Redo
Order of associating the material with the element	Applying the material
Applying the material	Irreversible action information
Scroll	3D model menu options
Library options' caption	Accept/cancel new solution
Order of changing the doors	Order of changing the doors
Drag the material	"Customise" button
	Scroll
2	**P3- Frequent non-severe**
Start	(2x) "My projects"
Help	**P4- Non-severe nor frequent**
Home and Back buttons	Start
Cancel button on the customise room option	Help
Identification of rooms on the floorplan	Home and Back buttons
Logo	Cancel button on the customise room option

“Hide” icon	Identification of rooms on the floorplan
“My projects”	Logo
“Hide” button denomination	“Hide” icon
	“Hide” button denomination
1	**P5- Do not need to be resolved**
Icons in “my projects” interface	Icons in “my projects” interface
“My home”	“My home”
Apartment identification	Apartment identification
Number of occupants	Number of occupants
“Choices made” identification	“Choices made” identification
3D orthographic views	3D orthographic views
“Continue customising” button	“Continue customising” button
Materials denomination	Materials denomination
Delete walls	Delete walls
Windows	Windows

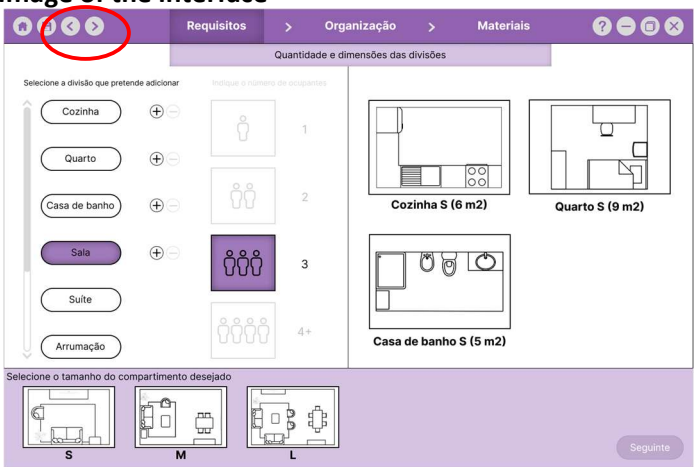
Warnings

PROBLEM DESIGNATION: Warnings
HEURISTICS VIOLATED: 5- Error Prevention (Nielsen’s Heuristics)
PROBLEM DESCRIPTION: When confirmation warnings appear about important and non-reversible actions, the button that draws the most attention (the one highlighted in dark purple) is “Accept”. Since the user may not pay attention to the text of the warning and has a tendency to click on the highlighted button, such a button should be the “Cancel” button to prevent the user from accidentally committing to an action that he did not intend.
SOLUTION PROPOSAL: Assign dark purple to the “Cancel” button instead of the “Accept” as it currently is.
SEVERITY DEGREE: 3
Image of the interface 

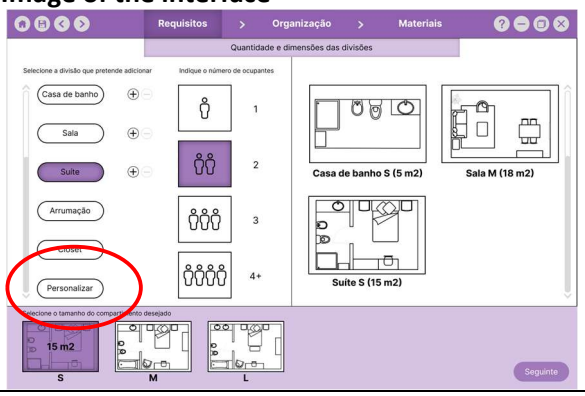
Irreversible action information

PROBLEM DESIGNATION: Irreversible action information
HEURISTICS VIOLATED: 5- Error Prevention (Nielsen's Heuristics)
PROBLEM DESCRIPTION: The warning does not indicate that the action is irreversible. The text of the warning must indicate this information so that the user is aware of the consequences of their decisions.
SOLUTION PROPOSAL: Add in the warning the information that when choosing a house, the user cannot change that decision later.
SEVERITY DEGREE: 3
Image of the interface 

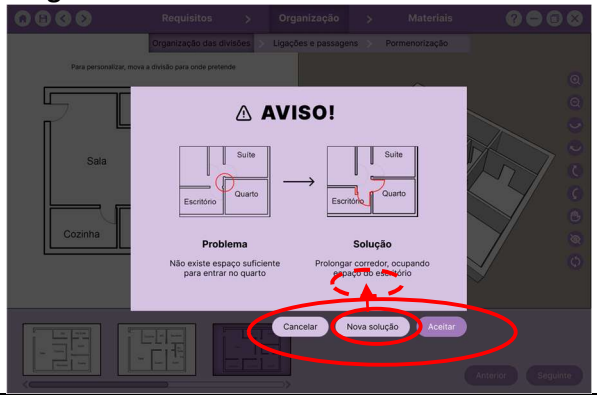
Undo/Redo

PROBLEM DESIGNATION: Undo/Redo
HEURISTICS VIOLATED: 4- Consistency and standards (Nielsen's Heuristics)
PROBLEM DESCRIPTION: Different features cannot have similar appearance - The Undo icon is the same as navigating backwards in previous stages. In addition to being the same, it is not consistent with other platforms that have the same functionality, not representing its function well
SOLUTION PROPOSAL: Change the Undo/Redo icons
SEVERITY DEGREE: 3
Image of the interface 

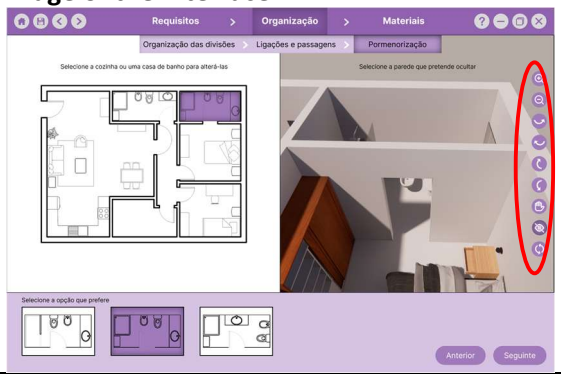
"Customise" button

PROBLEM DESIGNATION: "Customise" button
HEURISTICS VIOLATED: 4- Consistency and standards (Nielsen's Heuristics)
PROBLEM DESCRIPTION: Different functionalities cannot have similar appearances: Customise must not have the same appearance as the previous buttons, because it is intended to create a new label
SOLUTION PROPOSAL: Replace the name "personalizar" (Customise), for example, with a "+" so that it does not look like a button, like the previous ones
SEVERITY DEGREE: 3
Image of the interface 

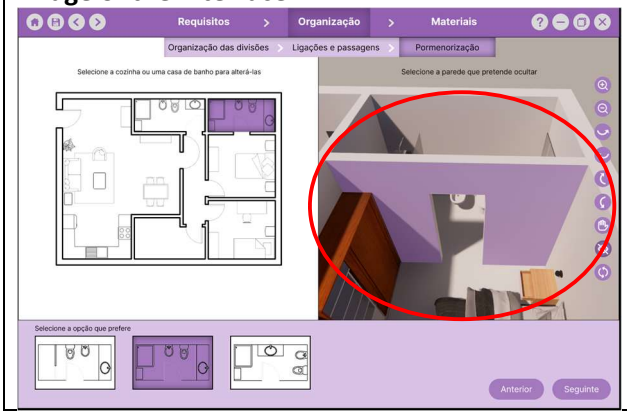
Accept/cancel new solution

PROBLEM DESIGNATION: Accept/cancel new solution
HEURISTICS VIOLATED: 2- Match between the system and the real world (Nielsen's Heuristics)
PROBLEM DESCRIPTION: When the warning appears, when changing the room with the suite, there are the options to cancel, generate a new solution, or accept. "Accept" means accepting the proposed solution (the design cannot be changed as the user changed it because it does not comply with the regulations), and "cancel" means cancelling the change that was made (exchanging the room with the suite) – This information is not clear with the buttons just saying "accept" and "cancel" The generate new solution button is also not clear about what it does and should not be grouped with the accept and cancel buttons
SOLUTION PROPOSAL: Change the name of the buttons to "accept proposed solution", "cancel change" and "generate alternative", and place the "generate alternative" button within the frame, below the solution
SEVERITY DEGREE: 3
Image of the interface 

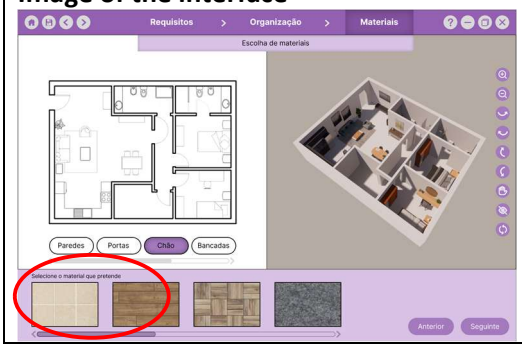
3D model menu options

PROBLEM DESIGNATION: 3D model menu options
HEURISTICS VIOLATED: 1- Visibility of the system status (Nielsen's Heuristics)
PROBLEM DESCRIPTION: The system must indicate that something has happened. In 3D, when the user wants to hide the wall, when he/she clicks on the "hide" button it changes colour (it becomes darker purple as it is selected) - this change is very subtle and the user does not notice that it has changed colour.
SOLUTION PROPOSAL: Intensify the button's state change, for example, making the line around it thicker
SEVERITY DEGREE: 3
Image of the interface 

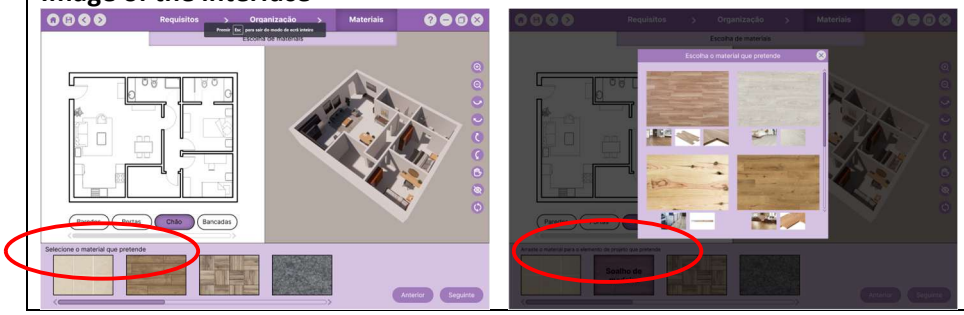
Order of hiding walls in the 3D view

PROBLEM DESIGNATION: Order of hiding walls in the 3D view
HEURISTICS VIOLATED: 7- Flexibility and efficiency of use (Nielsen's Heuristics)
PROBLEM DESCRIPTION: In *Detailing* (Pormenorização), some people tend to first choose the wall and then say what they want to do with it (hide it in 3D). On the other hand, some people do it the other way around (first click the *Hide* button and then select the wall they want to hide). Doing it in just one of the ways may make some users not know how to act.
SOLUTION PROPOSAL: The system should give the option to do it both ways, or the wall should automatically disappear (see the wall disappearing), because it is not mandatory to change the view, only if the user wants to see it better
SEVERITY DEGREE: 3
Image of the interface 

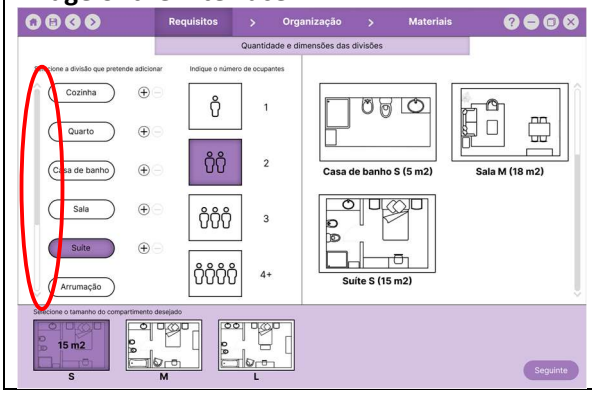
Order of associating the material with the element

PROBLEM DESIGNATION: Order of associating the material with the element
HEURISTICS VIOLATED: 7- Flexibility and efficiency of use (Nielsen's Heuristics)
PROBLEM DESCRIPTION: In *Materials*, the task is to choose a material for a room/element. By first choosing the material, the user considers the task complete because they have achieved the goal. However, it still needs to be associated with the room/design element.
SOLUTION PROPOSAL: Change the sequence of actions when choosing materials - first choose the room/design element where to place the material and then choose the material. Or allow both ways
SEVERITY DEGREE: 3
Image of the interface 

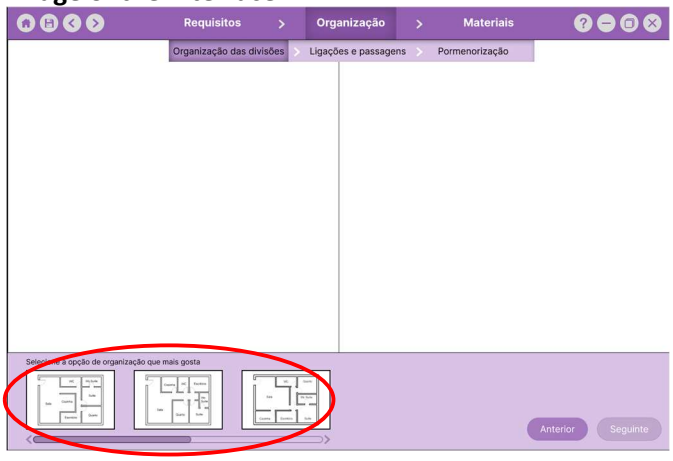
Applying the material

PROBLEM DESIGNATION: Applying the material
HEURISTICS VIOLATED: (1) 5- Error Prevention (Nielsen's Heuristics); **(2)** 8- Aesthetic and minimalist design (Nielsen's Heuristics)
PROBLEM DESCRIPTION: (1) It's not a good practice to drag something from the primary menu because it gives access to a set of options. If the user drags from this menu, they do not know which option they are assigning to the room. It must be dragged from the menu where the material option that the user chose is located. However, in this case, it cannot be dragged either because it is a popup menu and therefore is placed in front of the floorplan. **(2)** Furthermore, the number of functions per control must be minimised - the ideal would be one function per control - in this case, the material buttons have two functions: 1- click to open the pop-up menu and choose the option, and 2- drag to assign the material to the room.
SOLUTION PROPOSAL: Change the order in which the material is applied, i.e, first choose where the material will be applied and then select the material option (without dragging). Thus, when selected, the material is automatically associated with the previously chosen room/element.
SEVERITY DEGREE: 3
Image of the interface 

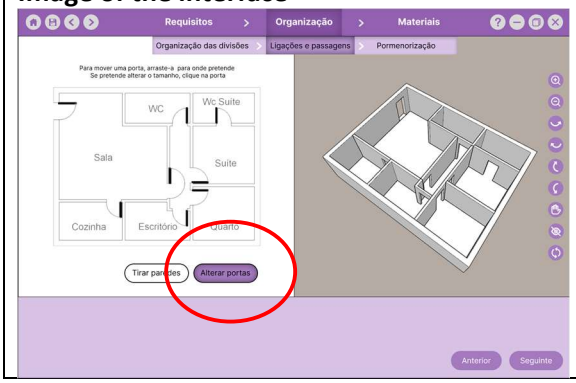
Scroll

PROBLEM DESIGNATION: Scroll
HEURISTICS VIOLATED: 1- Visibility of the system status (Nielsen's Heuristics)
PROBLEM DESCRIPTION: When functions are hidden, it is difficult for the user to discover and know how to use the interface. Scrolling should be avoided.
SOLUTION PROPOSAL: Divide information across more screens.
SEVERITY DEGREE: 3
Image of the interface 

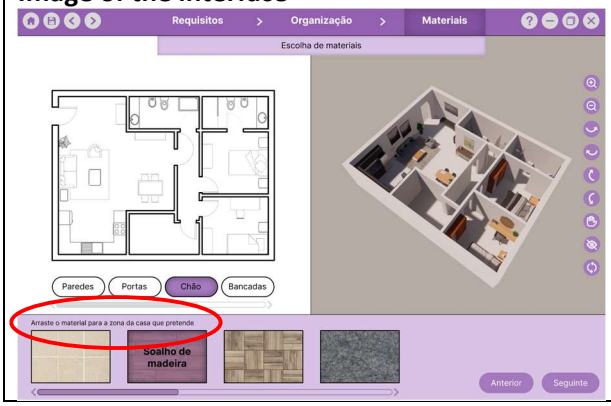
Library options' caption

PROBLEM DESIGNATION: Library options' caption
HEURISTICS VIOLATED: 6- Recognition rather than recall (Nielsen's Heuristics)
PROBLEM DESCRIPTION: Options are not identified. When sliding the scroll bar, what was the 3rd option is no longer in the 3rd position. The user should not have to memorise the options
SOLUTION PROPOSAL: Caption options
SEVERITY DEGREE: 3
Image of the interface 

Order of changing the doors

PROBLEM DESIGNATION: Order of changing the doors
HEURISTICS VIOLATED: 7- Flexibility and efficiency of use (Nielsen's Heuristics)
PROBLEM DESCRIPTION: In the connections and passages task, some people will first click on the "change doors" button, but there may also be a tendency to click on the door directly before selecting the button.
SOLUTION PROPOSAL: Allow both options – if the user clicks on the door directly, the system activates the button automatically
SEVERITY DEGREE: 3
Image of the interface 

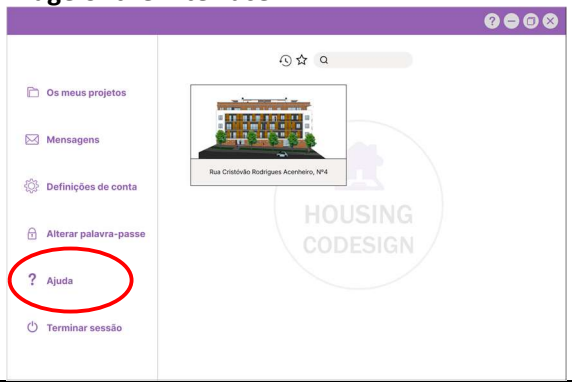
Drag the material

PROBLEM DESIGNATION: Drag the material
HEURISTICS VIOLATED: 1- Visibility of the system status (Nielsen's Heuristics)
PROBLEM DESCRIPTION: The sentence that tells the user to drag the material to the desired room, despite pulsing, does not stand out.
SOLUTION PROPOSAL: The sentence should be in another area of the interface (higher up), and highlighted (with bold or another colour that attracts attention)
SEVERITY DEGREE: 3
Image of the interface 

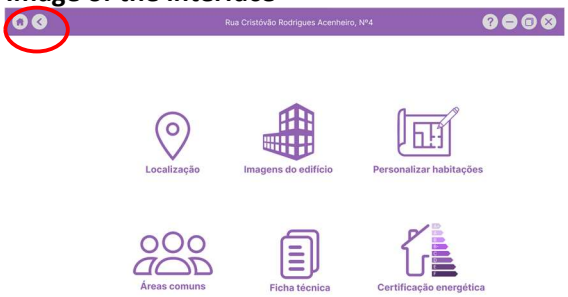
Start

PROBLEM DESIGNATION: Start
HEURISTICS VIOLATED: 1- Visibility of the system status (Nielsen's Heuristics)
PROBLEM DESCRIPTION: Right on the start, the user may think that the system is processing. There is no element that indicates the state of the system.
SOLUTION PROPOSAL: There should be a "start" button or something similar
SEVERITY DEGREE: 2
Image of the interface 

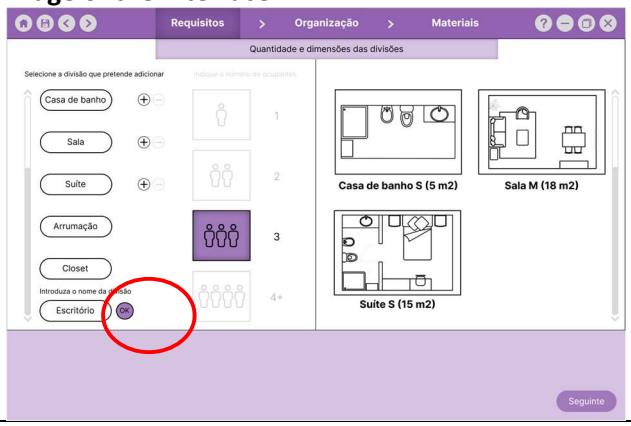
Help

PROBLEM DESIGNATION: Help
HEURISTICS VIOLATED: 4- Consistency and standards (Nielsen's Heuristics)
PROBLEM DESCRIPTION: In *My Projects*, there is a help tab and the help button (next to close, minimise and maximise) - it is redundant to have two helps
SOLUTION PROPOSAL: Remove the "Help" tab from the side menu
SEVERITY DEGREE: 2
Image of the interface 

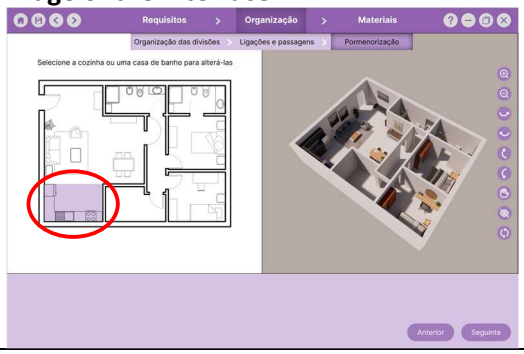
Home and Back buttons

PROBLEM DESIGNATION: Home and Back buttons
HEURISTICS VIOLATED: 4- Consistency and standards (Nielsen's Heuristics)
PROBLEM DESCRIPTION: Having "Home" and "Back" buttons is redundant because they will lead to the same place
SOLUTION PROPOSAL: Remove the "Home" button
SEVERITY DEGREE: 2
Image of the interface 

Cancel button on the customise room option

PROBLEM DESIGNATION: Cancel button on the customise room option
HEURISTICS VIOLATED: 3- User control and freedom (Nielsen's Heuristics)
PROBLEM DESCRIPTION: There is no option to cancel entering a custom room. It's not too serious because the user can delete the text they entered to name the room or click anywhere else in the interface, and the entry is cancelled.
SOLUTION PROPOSAL: Add a "Cancel" near "Ok" (does not need to be "Cancel" and "Ok", it can be a "√" and "X")
SEVERITY DEGREE: 2
Image of the interface 

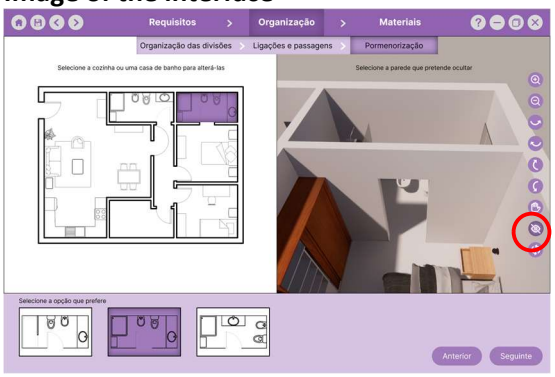
Identification of rooms on the floorplan

PROBLEM DESIGNATION: Identification of rooms on the floorplan
HEURISTICS VIOLATED: 6- Recognition rather than recall (Nielsen's Heuristics)
PROBLEM DESCRIPTION: In the detail phase, hovering the cursor over the rooms highlights them (on the floorplan). The room's name should also appear because the user should not have to remember where the kitchen was. If it is identified it is easier to recognise the room
SOLUTION PROPOSAL: Caption spaces on the floorplan when hovering the cursor over them
SEVERITY DEGREE: 2
Image of the interface 

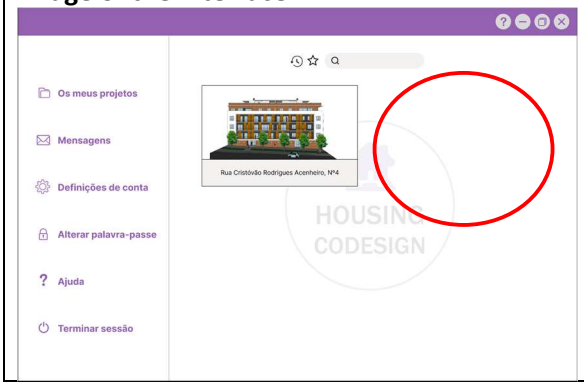
Logo

PROBLEM DESIGNATION: Logo
HEURISTICS VIOLATED: 2- Match between the system and the real world (Nielsen's Heuristics)
PROBLEM DESCRIPTION: The system must use the user's language. If the user is Portuguese, the logo in English can make participants feel withdrawn as they do not feel comfortable with English, and think that the entire interface will be in English.
SOLUTION PROPOSAL: Change to Portuguese
SEVERITY DEGREE: 2
Image of the interface 

“Hide” icon

PROBLEM DESIGNATION: “Hide” icon
HEURISTICS VIOLATED: 2- Match between the system and the real world (Nielsen’s Heuristics)
PROBLEM DESCRIPTION: The system must use the user's language. The wall hide button icon may not be recognised by the user. If the expert did not recognise it, it is possible that the user will not recognise it either. However, when hovering the cursor over it, the denomination of the button appears.
SOLUTION PROPOSAL: Change the icon so that it is clearer to the user
SEVERITY DEGREE: 2
Image of the interface 

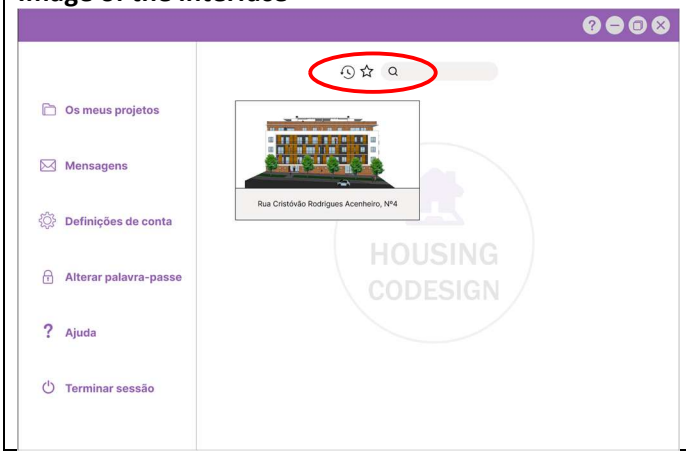
“My projects”

PROBLEM DESIGNATION: “My projects”
HEURISTICS VIOLATED: 3- User control and freedom (Nielsen’s Heuristics)
PROBLEM DESCRIPTION: In “my projects” there should be more options.
SOLUTION PROPOSAL: Add more projects options to choose from.
SEVERITY DEGREE: 2
Image of the interface 

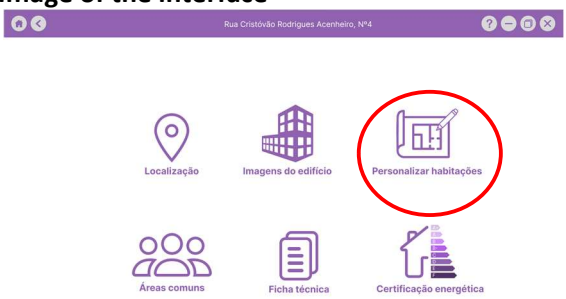
"Hide" button denomination

PROBLEM DESIGNATION: "Hide" button denomination
HEURISTICS VIOLATED: 1- Visibility of the system status (Nielsen's Heuristics)
PROBLEM DESCRIPTION: If the user hovers the cursor over the "hide" button when it is selected, the button designation does not appear. This may confuse the user, as they may not remember the button's function.
SOLUTION PROPOSAL: Add the button name similarly to what occurs with all other buttons in the 3D menu
SEVERITY DEGREE: 2
Image of the interface 

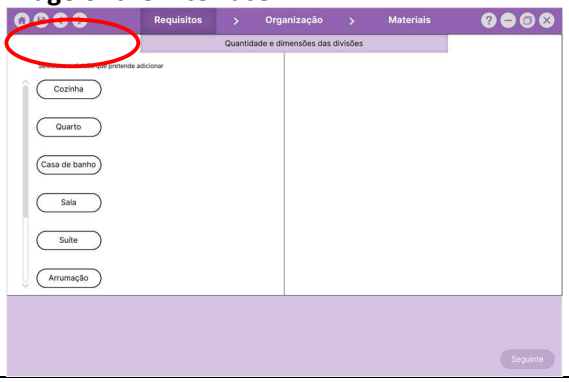
Icons in "my projects" interface

PROBLEM DESIGNATION: Icons in "my projects" interface
HEURISTICS VIOLATED: 8- Aesthetic and minimalist design (Nielsen's Heuristics)
PROBLEM DESCRIPTION: The icons concentrated in the center should be in another position
SOLUTION PROPOSAL: Position the icon group in the upper right corner, below the toolbar
SEVERITY DEGREE: 1
Image of the interface 

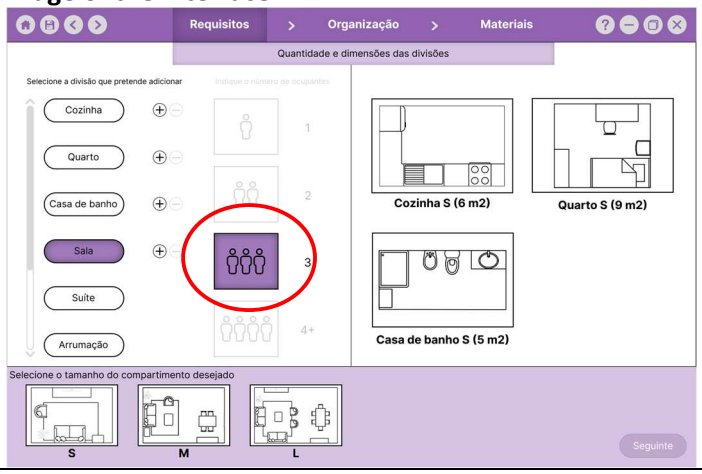
"My home"

PROBLEM DESIGNATION: "My home"
HEURISTICS VIOLATED: 2- Match between the system and the real world (Nielsen's Heuristics)
PROBLEM DESCRIPTION: After selecting the project, the option "customise houses" should be in the singular (customise house). The greater the evidence of an object, the better the identification of its use. In this case, this option must indicate that the user will only customise their house.
SOLUTION PROPOSAL: Change it to "Customize house" or "My house" (so it is not the only option that starts with an action)
SEVERITY DEGREE: 1
Image of the interface 

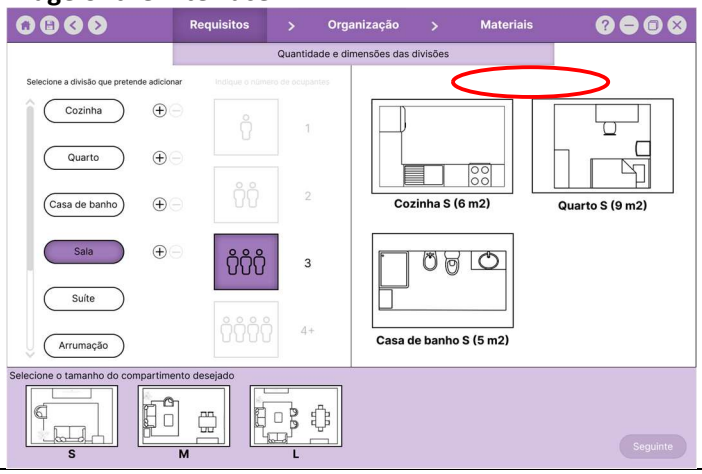
Apartment identification

PROBLEM DESIGNATION: Apartment identification
HEURISTICS VIOLATED: 6- Recognition rather than recall (Nielsen's Heuristics)
PROBLEM DESCRIPTION: When the house has already been chosen and we are already starting to customise the house, it should always be known which apartment has been chosen. The user should not be forced to remember what choice they made previously.
SOLUTION PROPOSAL: Add to the interface the identification of the apartment that is being customised (e.g. in the top left corner)
SEVERITY DEGREE: 1
Image of the interface 

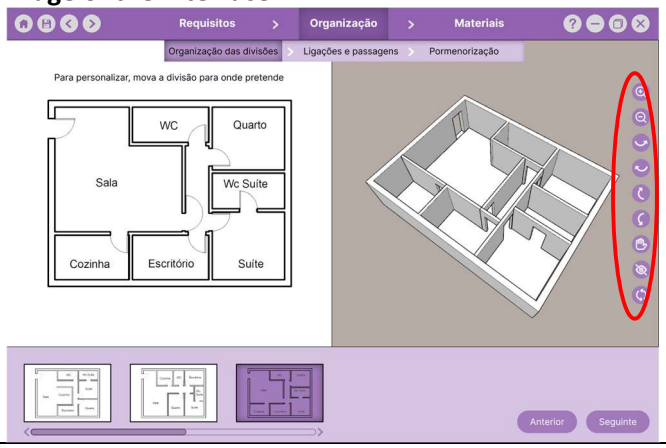
Number of occupants

PROBLEM DESIGNATION: Number of occupants
HEURISTICS VIOLATED: 1- Visibility of the system status (Nielsen's Heuristics)
PROBLEM DESCRIPTION: When choosing requirements, the user may be confused about why the number of occupants is previously selected and blocked. The system must provide this information
SOLUTION PROPOSAL: Place an indication that the number of occupants was defined (with the exception of bedrooms) depending on the household (e.g. when hovering the cursor over the button)
SEVERITY DEGREE: 1
Image of the interface 

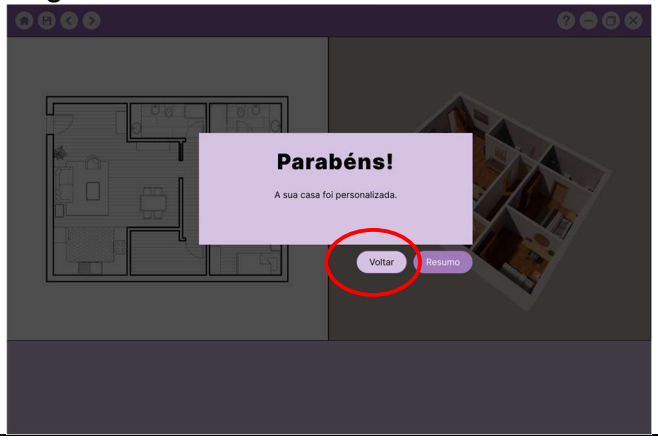
"Choices made" identification

PROBLEM DESIGNATION: "Choices made" identification
HEURISTICS VIOLATED: 1- Visibility of the system status (Nielsen's Heuristics)
PROBLEM DESCRIPTION: The user may not realise that the workspace on the right screen is where the summary of the choices appears. The system must provide this information
SOLUTION PROPOSAL: Place in the workspace on the right side: "summary of your choices"
SEVERITY DEGREE: 1
Image of the interface 

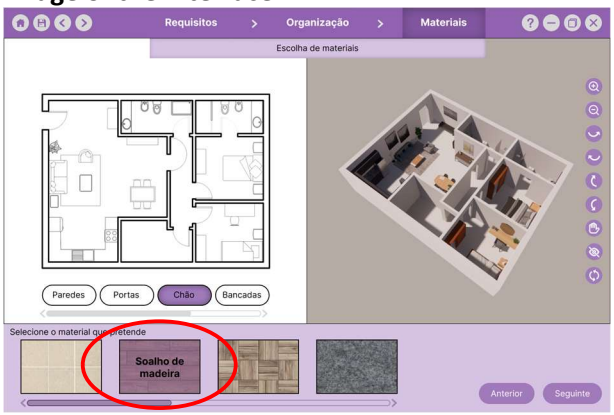
3D orthographic views

PROBLEM DESIGNATION: 3D orthographic views
HEURISTICS VIOLATED: Heuristics are not applied because it is a matter of architecture visualisation.
PROBLEM DESCRIPTION: In the 3D interaction menu, there should also be orthographic views - at least the top view
SOLUTION PROPOSAL: Add options for orthographic views
SEVERITY DEGREE: 1
Image of the interface 

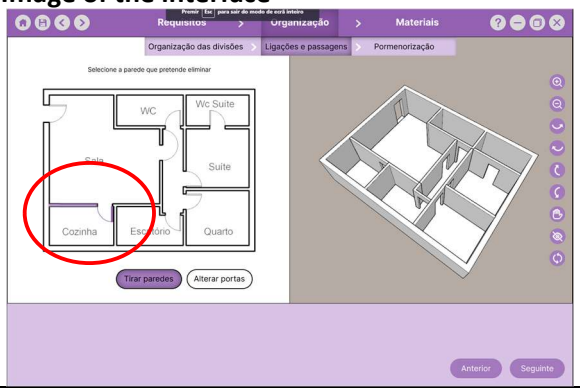
"Continue customising" button

PROBLEM DESIGNATION: "Continue customising" button
HEURISTICS VIOLATED: 2- Match between the system and the real world (Nielsen's Heuristics)
PROBLEM DESCRIPTION: Interface elements must be clear about what will happen if the user interacts with them. When finishing the project, after having chosen the finishing materials, the "Back" button is not clear about what happens if the user clicks on it.
SOLUTION PROPOSAL: Replace the name of the "Back" button with "Continue to customise"
SEVERITY DEGREE: 1
Image of the interface 

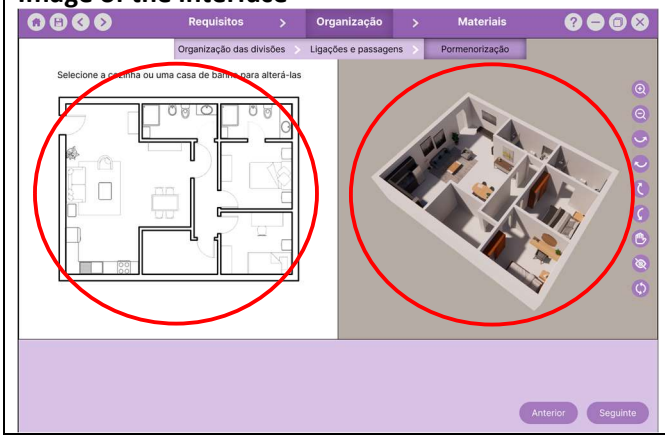
Materials denomination

PROBLEM DESIGNATION: Materials denomination
HEURISTICS VIOLATED: 2- Match between the system and the real world (Nielsen's Heuristics)
PROBLEM DESCRIPTION: Interface elements must clearly indicate their function so that the user has clues about their use. The materials should be identified in the plural (tiles, floors...), because in the singular they do not indicate to the user that there are options to choose from if they click on a certain type of material.
SOLUTION PROPOSAL: Correct designation of materials, putting them in the plural
SEVERITY DEGREE: 1
Image of the interface 

Delete walls

PROBLEM DESIGNATION: Delete walls
HEURISTICS VIOLATED: 2- Match between the system and the real world (Nielsen's Heuristics)
PROBLEM DESCRIPTION: It lacks relating the action to what would happen in the real world. When eliminating walls, the system must simulate what will happen to that wall.
SOLUTION PROPOSAL: Place the icon of an eraser, or a hammer for the person to erase (or destroy) the wall directly on the floorplan
SEVERITY DEGREE: 1
Image of the interface 

Windows

PROBLEM DESIGNATION: Windows
HEURISTICS VIOLATED: 2- Match between the system and the real world (Nielsen's Heuristics)
PROBLEM DESCRIPTION: Windows should be represented, as this may affect the choice of, e.g., the kitchen layout.
SOLUTION PROPOSAL: Change the representation of the architectural project
SEVERITY DEGREE: 1
Image of the interface 

Appendix D: Summative Evaluation Protocol

(Original Portuguese Version)

PROTOCOLO E EXPLICAÇÃO DA EXPERIÊNCIA

Este guião deve ser verbalizado pelo investigador aos participantes e poderá ser lido ou memorizado e dito, desde que a mesma informação chegue às pessoas que irão efetuar o teste.
"Antes de mais, quero agradecer a sua participação neste teste, a sua opinião é uma parte importante para o estudo que está a ser realizado. Irá participar na avaliação de uma ferramenta digital para o co-design de habitações, desenvolvida com base nos resultados das entrevistas feitas num estudo anterior.

Para contextualizar, estas entrevistas serviram para perceber como ocorrem os processos participativos e como uma ferramenta digital poderia ajudar os habitantes a participar no projeto das suas casas. Auxiliaram também a definição das partes do projeto sobre as quais os habitantes gostariam de tomar decisões, os dispositivos e os modos de interação e visualização com os quais se sentem mais confortáveis ao usar uma ferramenta digital para desenhar as suas casas.

O objetivo deste teste é perceber a sua opinião relativamente à ferramenta que lhe vai ser apresentada, nomeadamente em relação à facilidade de uso. Numa primeira fase, ser-lhe-á entregue um termo de consentimento, que deve ser lido e assinado se concordar com o conteúdo, para garantir que o teste é feito voluntariamente. Caso esteja de acordo, e depois de responder a um pequeno questionário preliminar, prosseguimos para a próxima fase onde lhe será pedido que realize algumas tarefas para que possa experimentar o protótipo e dar a sua opinião.

Solicito-lhe agora que leia o Termo de Consentimento, onde tem acesso à informação mais detalhada sobre objetivos e condições do estudo, e, caso concorde com tudo, assine e preencha o questionário preliminar."

[Entrega e assinatura do Termo de consentimento]

[Entrega e preenchimento do Questionário Preliminar]

Antes de serem fornecidas tarefas ao participante, o investigador deverá dar as seguintes instruções:

"Vou agora passar à explicação de como a experiência vai ocorrer: Este é o protótipo que irá ser avaliado. Vai ter a oportunidade de experimentá-lo através da realização de dez tarefas simples, que estão descritas num guião que lhe vou disponibilizar no início da experiência. São cinco ecrãs, que correspondem às cinco fases do projeto com as quais irá interagir: a definição de

requisitos, organização dos espaços, ligações e passagens, pormenorização dos espaços e escolha de materiais. Em cada um é necessário fazer alguns passos para concretizar a tarefa.
Enquanto estiver a realizá-las, vai ser acompanhado por uma simulação da resposta do sistema às suas ações. Peço-lhe que preste atenção a todos os elementos do "ecrã" e às indicações que vão surgindo, porque eu não posso ajudar na realização das tarefas, uma vez que o que está a ser avaliado é a capacidade que o sistema tem de transmitir como se deve proceder. Reforço que em nenhum momento está a ser avaliado(a). O único alvo de avaliação neste teste é a ferramenta. Peço-lhe também que durante a realização das tarefas diga em voz alta o que está a pensar e quais as suas dificuldades e opiniões que surgem no momento.
Após a realização de cada tarefa, deve responder a um pequeno questionário que lhe será igualmente disponibilizado. Deve ser respondido logo após a realização de cada tarefa, porque é quando a informação ainda está fresca na memória. Se não conseguir completar uma tarefa, não se preocupe, passaremos à próxima. Quando terminar, ser-lhe-á pedido que responda a um pequeno questionário final de satisfação em relação à ferramenta em geral.
Caso tenha alguma dúvida, esteja à vontade para colocá-la. Quando estiver pronto, podemos iniciar a experiência".

[Entrega do Guião de tarefas]

[Entrega do Questionário SEQ]

[Realização das tarefas e resposta ao Questionário SEQ por parte do participamte]

[Entrega do Questionário SUS]

[Entrega do Questionário GUI]

"Diga por favor, os três aspetos que mais gostou"

[Anotar]

1-

2-

3-

"Diga por favor os três aspetos que menos gostou"

[Anotar]

1-

2-

3-

(Translated English Version)

PROTOCOL AND EXPERIENCE EXPLANATION

This script should be spoken by the researcher to participants. It may be read aloud or memorised and recited, as long as the same information is conveyed to those taking part in the test.

“First of all, I want to thank you for participating in this test. Your opinion is an important part of the study being conducted. You will participate in evaluating a digital tool for co-designing housing, based on the results of interviews conducted in a previous study.

To provide context, those interviews aimed to understand how participatory processes occur and how a digital tool could help residents take part in designing their houses. They also helped define which parts of the project residents would like to make decisions about, as well as the devices, interaction modes, and visualisation methods they feel most comfortable using when working with a digital tool to design their homes.

The goal of this test is to understand your opinion about the tool that will be presented to you, particularly regarding its ease of use. In the first phase, you’ll be given a consent form, which you should read and sign if you agree with its contents, to ensure the test is conducted voluntarily. If you agree, and after completing a short preliminary questionnaire, we’ll move on to the next phase, where you’ll be asked to perform a few tasks so you can try out the prototype and share your opinion.

I now ask you to read the Consent Form, which contains more detailed information about the study’s objectives and conditions. If you agree with everything, please sign it and fill out the preliminary questionnaire.

[Provision and signature of the Consent Form]

[Provision and completion of the Preliminary Questionnaire]

Before tasks are given to the participant, the researcher should provide the following instructions:

“I will now explain how the experience will unfold: This is the prototype that will be evaluated. You will have the opportunity to try it out by completing ten simple tasks, which are described in a script I will provide at the beginning of the experience. There are five screens, each corresponding to one of the five project phases you will interact with: requirements definition, space organisation, connections and pathways, space detailing, and material selection. Each screen involves a few steps to complete the task.

While performing the tasks, you will be accompanied by a simulation of the system's response to your actions. Please pay close attention to all elements on the screen and to the instructions that appear, because I will not be able to help you during the tasks, since what is being evaluated is the system's ability to communicate how to proceed. I want to emphasise that you are not being evaluated at any point. The only subject of evaluation in this test is the interface. I also ask that, while performing the tasks, you speak aloud about what you are thinking, any difficulties you encounter, and any opinions that arise in the moment.

After completing each task, you will be asked to fill out a short questionnaire, which should be completed immediately after each task while the information is still fresh in your memory. If you are unable to complete a task, don't worry, we will move on to the next one. Once you have finished, you will be asked to complete a short final satisfaction questionnaire about the tool overall.

If you have any questions, feel free to ask. When you are ready, we can begin the experience."

[Provision of the Task Script]

[Provision of SEQ Questionnaire]

[Execution of tasks and completion of the SEQ Questionnaire by the participant]

[Provision and filling of the SUS Questionnaire]

[Provision and filling of the GUI Questionnaire]

"Please identify the three aspects of the tool you appreciated most."

[Record responses]

1.

2.

3.

"Please identify the three aspects of the tool you appreciated least."

[Record responses]

1.

2.

3.

(Original Portuguese Version)

QUESTIONÁRIO PRELIMINAR

Número de participante:

Idade

☐ 25 – 30
☐ 31 – 35
☐ 36 – 40
☐ 41 – 45

Género

☐ Masculino
☐ Feminino
☐ Outro (Por favor, especifique) _____

Qual é o seu nível de escolaridade?

☐ Até ao 9º ano
☐ Até ao 12º ano
☐ Ensino superior

Qual é a sua profissão/formação?

_____

Como avalia a sua relação com as tecnologias digitais?

☐ Muito má
☐ Insuficiente
☐ Razoável
☐ Boa
☐ Muito Boa

Alguma vez teve contato com projetos de arquitetura?

☐ Sim
☐ Não

Neste momento sinto-me … (assinalar as que se aplicam)

☐ Motivado(a)
☐ Apreensivo(a)
☐ Outro (Por favor especifique) _____

Obrigado pela sua participação!

(Translated English Version)

PRELIMINARY QUESTIONNAIRE

Participant number:

Age

☐ 25 – 30
☐ 31 – 35
☐ 36 – 40
☐ 41 – 45

Gender

☐ Male
☐ Female
☐ Other (Please, specify) _____

What is your education level?

☐ Until 9th grade
☐ Between 9th and 12th grade
☐ Higher education

What is your profession /training?

_____

How do you evaluate your relationship with digital technologies?

☐ Very bad
☐ Insufficient
☐ Reasonable
☐ Good
☐ Very Good

Have you ever had contact with architectural projects?

☐ Yes
☐ No

At this moment I feel… (check those that apply)

☐ Motivated
☐ Apprehensive
☐ Other (Please, specify) _____

Thank you for your participation!

(Original Portuguese Version)

GUIÃO DE TAREFAS

Imagine que se juntou recentemente a uma cooperativa de habitação e vai ser construído um edifício de apartamentos. Vai utilizar este sistema para personalizar a sua casa. Imagine que as escolhas indicadas nas tarefas abaixo seriam as opções que prefere e, por isso, as escolheu. Imagine também que pretende uma casa para um agregado familiar de **3 pessoas**. A escolha da casa é feita por ordem de sócio, pelo que poderá haver opções indisponíveis para escolher.

Tarefas a serem realizadas pelo participante:

- ➔ **Tarefa 1:** Inicie sessão com os seguintes dados de acesso:
  Email: exemplo@codesign.pt
  Palavra-passe: participar
- ➔ **Tarefa 2:** Imagine que vai escolher a sua habitação, e pretende ficar com o apartamento 1D (T2), no piso 1, do projeto da Rua Cristóvão Rodrigues Acenheiro
- ➔ **Tarefa 3:**
  - Imagine que pretende ter na sua casa uma cozinha com o tamanho **S**
  - Imagine que pretende ter na sua casa um quarto para uma pessoa com o tamanho **S**
  - Imagine que pretende ter na sua casa uma casa de banho com o tamanho **S**
  - Imagine que pretende ter na sua casa uma sala com o tamanho **M**
  - Imagine que pretende ter na sua casa uma suíte para duas pessoas com o tamanho **S**
- ➔ **Tarefa 4:** Imagine que, além das divisões disponíveis, pretende adicionar uma divisão personalizada com o nome "escritório" e que esta tenha o tamanho **S**.
  Siga para a próxima fase
- ➔ **Tarefa 5:** Imagine que a opção que mais gostou foi a opção 3. Escolha-a e personalize trocando o quarto com a suite.
  Siga para a próxima fase
- ➔ **Tarefa 6:** Imagine que não gostou da posição da porta entre a sala e o corredor. Altere-a para perto do wc. Imagine que está satisfeito com o tamanho da porta e, por isso, mantenha-a com o tamanho S.

➔ **Tarefa 7:** Imagine que pretende eliminar a parede entre a sala e a cozinha. Tire a parede para ligar estes espaços.
Siga para a próxima fase

➔ **Tarefa 8:**

- Imagine que pretende trocar o formato da cozinha por uma cozinha em "U".
- Imagine que pretende trocar a disposição da casa de banho da suíte e que gostou mais da primeira opção.
- Imagine que pretende trocar a disposição da casa de banho que liga ao corredor e que gostou mais da terceira opção.

Siga para a próxima fase

➔ **Tarefa 9:** Imagine que pretende colocar soalho de madeira no chão da sua sala e gostou mais do primeiro tipo de soalho.

➔ **Tarefa 10:** Imagine que já escolheu todos os materiais para a sua casa. Finalize o processo de personalização da sua casa e depois submeta o projeto

(Translated English Version)

TASKS SCRIPT

Imagine that you have recently joined a housing cooperative and an apartment building is going to be built. You will use this system to customise your house. Imagine that the choices indicated in the tasks below would be the options you prefer and therefore you chose them. Also, imagine that you want a house for a household of **3 people**. The choice of the house is made by member order, so there may be unavailable options to choose from.

Tasks to be performed by the participant:

- ➔ **Task 1:** Log in with the following access data:
  Email: exemplo@codesign.pt
  Password: participar
- ➔ **Task 2:** Imagine that you are going to choose your house, and you choose apartment 1D (T2), on the 1st floor, in the project at *Rua Cristóvão Rodrigues Acenheiro*
- ➔ **Task 3:**
  - Imagine you want to have in your house a kitchen with the size **S**
  - Imagine you want to have in your house a bedroom for one person with the size **S**
  - Imagine you want to have in your house a bathroom with the size **S**
  - Imagine you want to have in your house a living room with the size **M**
  - Imagine you want to have in your house a suite for two persons with the size **S**
- ➔ **Task 4:** Imagine that, besides the available rooms, you want to add a customized room with the name “office” and that it has the size **S.**
  Go to the next phase
- ➔ **Task 5:** Imagine that the option you liked the most was option 3. Choose it and customise it by switching the bedroom and the suite.
  Go to the next phase
- ➔ **Task 6:** Imagine that you didn't like the position of the door between the living room and the hallway. Change it to near the toilet. Imagine that you are satisfied with the size of the door, so keep it with the S size.
- ➔ **Task 7:** Imagine that you want to remove the wall between the living room and the kitchen. Remove the wall to connect these spaces.
  Go to the next phase

➔ **Task 8:**

- Imagine that you want to change the kitchen format for a “U” kitchen
- Imagine that you want to change the layout of the bathroom in the suite and you liked the first option.
- Imagine that you want to change the layout of the bathroom that connects to the hallway and that you liked the third option.

Go to the next phase

➔ **Task 9:** Imagine that you want to put a wooden floor on the floor of your living room and you liked the first type of wooden floor.

➔ **Task 10:** Imagine that you have already chosen all the materials for your home. Finalize the process of customizing your home and then submit the project

(Original Portuguese Version)

QUESTIONÁRIO SINGLE EASE QUESTION (SEQ)

Número de participante:

Por favor, responda a cada pergunta após a realização de cada tarefa.

Tarefa 1

De uma forma geral, quão fácil ou difícil foi realizar esta tarefa?

Muito difícil						Muito fácil
1	2	3	4	5	6	7

Tarefa 2

De uma forma geral, quão fácil ou difícil foi realizar esta tarefa?

Muito difícil						Muito fácil
1	2	3	4	5	6	7

Tarefa 3

De uma forma geral, quão fácil ou difícil foi realizar esta tarefa?

Muito difícil						Muito fácil
1	2	3	4	5	6	7

Tarefa 4

De uma forma geral, quão fácil ou difícil foi realizar esta tarefa?

Muito difícil						Muito fácil
1	2	3	4	5	6	7

Tarefa 5

De uma forma geral, quão fácil ou difícil foi realizar esta tarefa?

Muito difícil						Muito fácil
1	2	3	4	5	6	7

Tarefa 6

De uma forma geral, quão fácil ou difícil foi realizar esta tarefa?

Muito difícil Muito fácil

1	2	3	4	5	6	7

Tarefa 7

De uma forma geral, quão fácil ou difícil foi realizar esta tarefa?

Muito difícil Muito fácil

1	2	3	4	5	6	7

Tarefa 8

De uma forma geral, quão fácil ou difícil foi realizar esta tarefa?

Muito difícil Muito fácil

1	2	3	4	5	6	7

Tarefa 9

De uma forma geral, quão fácil ou difícil foi realizar esta tarefa?

Muito difícil Muito fácil

1	2	3	4	5	6	7

Tarefa 10

De uma forma geral, quão fácil ou difícil foi realizar esta tarefa?

Muito difícil Muito fácil

1	2	3	4	5	6	7

Obrigado pela sua participação!

(Translated English Version)

SINGLE EASE QUESTION (SEQ) QUESTIONNAIRE

Participant number:

Please answer each question after completing each task.

Task 1

Overall, how easy or difficult was it to accomplish this task?

Very difficult						Very easy
1	2	3	4	5	6	7

Task 2

Overall, how easy or difficult was it to accomplish this task?

Very difficult						Very easy
1	2	3	4	5	6	7

Task 3

Overall, how easy or difficult was it to accomplish this task?

Very difficult						Very easy
1	2	3	4	5	6	7

Task 4

Overall, how easy or difficult was it to accomplish this task?

Very difficult						Very easy
1	2	3	4	5	6	7

Task 5

Overall, how easy or difficult was it to accomplish this task?

Very difficult						Very easy
1	2	3	4	5	6	7

Task 6

Overall, how easy or difficult was it to accomplish this task?

Very difficult						Very easy
1	2	3	4	5	6	7

Task 7

Overall, how easy or difficult was it to accomplish this task?

Very difficult						Very easy
1	2	3	4	5	6	7

Task 8

Overall, how easy or difficult was it to accomplish this task?

Very difficult						Very easy
1	2	3	4	5	6	7

Task 9

Overall, how easy or difficult was it to accomplish this task?

Very difficult						Very easy
1	2	3	4	5	6	7

Task 10

Overall, how easy or difficult was it to accomplish this task?

Very difficult						Very easy
1	2	3	4	5	6	7

Thank you for your participation!

(Original Portuguese Version)

QUESTIONÁRIO SYSTEM USABILITY SCALE (SUS)

Número de participante:

Para cada uma das afirmações abaixo, selecione a caixa (apenas uma por linha) que melhor descreve a sua opinião relativamente à ferramenta que acabou de experimentar:

	Discordo totalmente				Concordo totalmente
1- Eu acho que gostaria de usar este sistema com frequência					
	1	2	3	4	5
2- Eu achei este sistema desnecessariamente complexo					
	1	2	3	4	5
3- Eu achei o sistema fácil de usar					
	1	2	3	4	5
4- Eu acho que precisaria de suporte de um técnico para conseguir usar o sistema					
	1	2	3	4	5
5- Eu achei que as várias funções do sistema estão bem integradas					
	1	2	3	4	5
6- Eu achei que o sistema apresenta muitas inconsistências					
	1	2	3	4	5
7- Eu imagino que as pessoas aprenderiam a usar este sistema rapidamente					
	1	2	3	4	5
8- Eu achei que o sistema era complicado de usar					
	1	2	3	4	5
9- Eu senti-me muito confiante a utilizar o sistema					
	1	2	3	4	5
10- Eu precisei aprender muitas coisas antes de conseguir utilizar o sistema					
	1	2	3	4	5

Obrigado pela sua participação!

(Translated English Version)

SYSTEM USABILITY SCALE (SUS) QUESTIONNAIRE

Participant number:

For each of the statements below, select the box (only one per line) that best describes your opinion about the tool you just tried:

	Totally disagree				Totally Agree
1- I think that I would like to use this system frequently					
	1	2	3	4	5
2- I found the system unnecessarily complex					
	1	2	3	4	5
3- I thought the system was easy to use					
	1	2	3	4	5
4- I think that I would need the support of a technical person to be able to use this system					
	1	2	3	4	5
5- I found the various functions in this system were well integrated					
	1	2	3	4	5
6- I thought there was too much inconsistency in this system					
	1	2	3	4	5
7- I would imagine that most people would learn to use this system very quickly					
	1	2	3	4	5
8- I found the system very cumbersome to use					
	1	2	3	4	5
9- I felt very confident using the system					
	1	2	3	4	5
10- I needed to learn a lot of things before I could get going with this system					
	1	2	3	4	5

Thank you for your participation!

(Original Portuguese Version)

QUESTIONÁRIO GRAPHICAL USER INTERFACE (GUI)

Número de participante:

Para cada uma das afirmações abaixo, selecione a caixa (apenas uma por linha) que melhor descreve a sua opinião relativamente à ferramenta que acabou de experimentar:

	Discordo totalmente				Concordo totalmente
1- Eu entendi os nomes das fases do projeto.					
	1	2	3	4	5
2- Não é fácil navegar pelos menus.					
	1	2	3	4	5
3- Eu entendi as opções e indicações do menu.					
	1	2	3	4	5
4- Os ícones e botões do menu não indicam claramente a sua função					
	1	2	3	4	5
5- Os gráficos e diagramas são fáceis de ler e entender					
	1	2	3	4	5
6- O design gráfico dos ecrãs não está bem desenhado					
	1	2	3	4	5
7- As informações estão bem organizadas nos ecrãs					
	1	2	3	4	5
8- Não é fácil aceder às informações de que preciso					
	1	2	3	4	5
9- O tamanho dos botões e das palavras ou frases é adequado					
	1	2	3	4	5

Obrigado pela sua participação!

(Translated English Version)

GRAPHICAL USER INTERFACE (GUI) QUESTIONNAIRE

Participant number:

For each of the statements below, select the box (only one per line) that best describes your opinion about the tool you just tried:

	Totally disagree				Totally Agree
1- I understood the names of the design phases					
	1	2	3	4	5
2- It's not easy to navigate through the menus					
	1	2	3	4	5
3- I understood the menu options and instructions.					
	1	2	3	4	5
4- Menu icons and buttons do not clearly indicate their function					
	1	2	3	4	5
5- Graphics and diagrams are easy to read and understand					
	1	2	3	4	5
6- The screen graphical design is not well designed					
	1	2	3	4	5
7- The information is well organized on the screens					
	1	2	3	4	5
8- It is not easy to access the information I need					
	1	2	3	4	5
9- The size of the buttons and words or statements is appropriate					
	1	2	3	4	5

Thank you for your participation

(Original Portuguese Version)

GRELHA DE REGISTO DE REALIZAÇÃO DE TAREFA

Número de participante:

Tarefa 1

Passos	Realizado	Não realizado	Tentativas*	Tempo
Clicar em Iniciar				
Clicar no campo “Email”				
Escrever “exemplo@codesign.pt” no teclado				
Clicar no campo “palavra passe” **OU** pressionar tecla Tab **OU** pressionar a tecla Enter				
Escrever “participar”				
Clicar no botão “iniciar sessão” **OU** pressionar a tecla Enter				
Notas: (comentários do participante durante a realização da tarefa, comportamentos, etc)				

*Assinalar o número de ações realizadas até realizar a ação correta. Se o participante não conseguir realizar a tarefa após três tentativas, registar como não concluída, e passar à seguinte

Tarefa 2

Passos	Realizado	Não realizado	Tentativas*	Tempo
Clicar em “Os meus projetos”				
Selecionar o projeto				
Clicar em “A minha habitação”				
Clicar na seta para a direita (para ir para o piso 1)				
Clicar sobre o apartamento 1D (T2)				
(surge um aviso)				
Clicar no botão “aceitar”				
Notas: (comentários do participante durante a realização da tarefa, comportamentos, etc)				

*Assinalar o número de ações realizadas até realizar a ação correta. Se o participante não conseguir realizar a tarefa após três tentativas, registar como não concluída, e passar à seguinte

Tarefa 3

Passos	Realizado	Não realizado	Tentativas*	Tempo
Clicar no botão “cozinha”				
Clicar na opção S para aparecer na área de escolhas				
Clicar no botão “Quarto”				
Clicar no botão de 1 pessoa				
Clicar na opção S para aparecer na área de escolhas				
Clicar no botão “Casa de banho”				
Clicar na opção S para a área de escolhas				
Clicar no botão “Sala”				
Clicar na opção M para aparecer na área de escolhas				
Clicar no botão “Suíte”				
Clicar no botão de 2 pessoas				
Clicar na opção S para aparecer na área de escolhas				
Notas: (comentários do participante durante a realização da tarefa, comportamentos, etc)				

*Assinalar o número de ações realizadas até realizar a ação correta. Se o participante não conseguir realizar a tarefa após três tentativas, registar como não concluída, e passar à seguinte

Tarefa 4

Passos	Realizado	Não realizado	Tentativas*	Tempo
Deslizar barra de deslizamento para procurar a opção “personalizar”				
Clicar em “+” para adicionar divisão personalizada				
Clicar em “personalizar” e escrever “escritório”				
Clicar no botão de confirmação **OU** pressionar a tecla Enter				
Clicar na opção S para aparecer na área de escolhas				
Clicar no botão “seguinte” no canto inferior direito, para passar à próxima fase				
Notas: (comentários do participante durante a realização da tarefa, comportamentos, etc)				

*Assinalar o número de ações realizadas até realizar a ação correta. Se o participante não conseguir realizar a tarefa após três tentativas, registar como não concluída, e passar à seguinte

Tarefa 5

Passos	Realizado	Não realizado	Tentativas*	Tempo
Clicar na "opção 3" para aparecer na área de interação				
Arrastar a suíte para o lugar do quarto individual ou vice-versa				
(surge um aviso)				
Clicar em "aceitar"				
Clicar no botão "seguinte" no canto inferior direito, para passar à próxima fase				
Notas: (comentários do participante durante a realização da tarefa, comportamentos, etc)				

*Assinalar o número de ações realizadas até realizar a ação correta. Se o participante não conseguir realizar a tarefa após três tentativas, registar como não concluída, e passar à seguinte

Tarefa 6

Passos	Realizado	Não realizado	Tentativas*	Tempo
Clicar em "alterar portas"				
Arrastar a porta do corredor para perto do wc				
Notas: (comentários do participante durante a realização da tarefa, comportamentos, etc)				

*Assinalar o número de ações realizadas até realizar a ação correta. Se o participante não conseguir realizar a tarefa após três tentativas, registar como não concluída, e passar à seguinte

Tarefa 7

Passos	Realizado	Não realizado	Tentativas*	Tempo
Clicar em "Tirar paredes"				
Clicar na parede entre a sala e a cozinha				
(surge um aviso)				
Clicar em “aceitar”				
Clicar no botão "seguinte" no canto inferior direito para passar à próxima fase				
Notas: (comentários do participante durante a realização da tarefa, comportamentos, etc)				

*Assinalar o número de ações realizadas até realizar a ação correta. Se o participante não conseguir realizar a tarefa após três tentativas, registar como não concluída, e passar à seguinte

Tarefa 8

Passos	Realizado	Não realizado	Tentativas*	Tempo
Clicar em cima da cozinha para selecioná-la				
Clicar na opção de cozinha em U, para substituí-la				
Clicar em cima do wc da suíte para selecioná-lo				
Clicar na primeira opção do wc da suite para substituí-lo				
Clicar em cima do wc social para selecioná-lo				
Clicar na terceira opção do wc social para substituí-lo				
Clicar no botão "seguinte" no canto inferior direito para passar à próxima fase				
Notas: (comentários do participante durante a realização da tarefa, comportamentos, etc)				

*Assinalar o número de ações realizadas até realizar a ação correta. Se o participante não conseguir realizar a tarefa após três tentativas, registar como não concluída, e passar à seguinte

Tarefa 9

Passos	Realizado	Não realizado	Tentativas*	Tempo
Clicar no botão “chão”				
Clicar na sala para selecionar a divisão				
Clicar na opção “Soalho de madeira”				
Selecionar a primeira opção				
Notas: (comentários do participante durante a realização da tarefa, comportamentos, etc)				

*Assinalar o número de ações realizadas até realizar a ação correta. Se o participante não conseguir realizar a tarefa após três tentativas, registar como não concluída, e passar à seguinte

Tarefa 10

Passos	Realizado	Não realizado	Tentativas*	Tempo
Clicar no botão "finalizar" no canto inferior direito para passar à próxima fase				
Surge um aviso				
Clicar em “Resumo”				
Clicar em “Submeter”				
Clicar no botão Voltar para os meus projetos **OU** na cruz para fechar a janela				
Notas: (comentários do participante durante a realização da tarefa, comportamentos, etc)				

*Assinalar o número de ações realizadas até realizar a ação correta. Se o participante não conseguir realizar a tarefa após três tentativas, registar como não concluída, e passar à seguinte

(Translated English Version)

TASK COMPLETION RECORD GRID

Participant number:

Task 1

Steps	Completed	Not Completed	Tentatives*	Time
Click Start				
Click on the “Email” field				
Type “exemplo@codesign.pt” on the keyboard				
Click on the “password” field **OR** press Tab key **OR** press Enter key				
Write “participar”				
Click on the “login” button OR press the Enter key				
Observations: Participant's comments during task execution, behaviours, etc.				

*Record the number of actions taken until the correct action is completed. If the participant is unable to complete the step within three attempts, mark it as incomplete and proceed to the next one

Task 2

Steps	Completed	Not Completed	Tentatives*	Time
Click on “My projects”				
Select the project				
Click on “My house”				
Click the right arrow (to go to floor 1)				
Click on apartment 1D (T2)				
(a warning appears)				
Click on the “accept” button				
Observations: Participant's comments during task execution, behaviours, etc.				

*Record the number of actions taken until the correct action is completed. If the participant is unable to complete the step within three attempts, mark it as incomplete and proceed to the next one

Task 3

Steps	Completed	Not Completed	Tentatives*	Time
Click on the “kitchen” button				
Click on the S option to appear in the choices area				
Click on the “Bedroom” button				
Click on the 1 person button				
Click on the S option to appear in the choices area				
Click on the “Bathroom” button				
Click on the S option to appear in the choices area				
Click on the “Livingroom” button				
Click on the M option to appear in the choices area				
Click on the “Suite” button				
Click on the 2 people button				
Click on the S option to appear in the choices area				
Observations: Participant's comments during task execution, behaviours, etc.				

*Record the number of actions taken until the correct action is completed. If the participant is unable to complete the step within three attempts, mark it as incomplete and proceed to the next one

Task 4

Steps	Completed	Not Completed	Tentatives*	Time
Swipe the slider to find the “customise” option				
Click “+” to add custom room				
Click on “customise” and write “office”				
Click the confirm button OR press the Enter key				
Click on the S option to appear in the choices area				
Clicking the “next” button in the bottom right corner to move on to the next phase				
Observations: Participant's comments during task execution, behaviours, etc.				

*Record the number of actions taken until the correct action is completed. If the participant is unable to complete the step within three attempts, mark it as incomplete and proceed to the next one

Task 5

Steps	Completed	Not Completed	Tentatives*	Time
Click on “option 3” to appear in the interaction area				
Drag the suite to the single room's place or vice versa				
(a warning appears)				
Click “accept”				
Clicking the “next” button in the bottom right corner to move on to the next phase				
Observations: Participant's comments during task execution, behaviours, etc.				

*Record the number of actions taken until the correct action is completed. If the participant is unable to complete the step within three attempts, mark it as incomplete and proceed to the next one

Task 6

Steps	Completed	Not Completed	Tentatives*	Time
Click on “change doors”				
Drag the hallway door closer to the bathroom				
Observations: Participant's comments during task execution, behaviours, etc.				

*Record the number of actions taken until the correct action is completed. If the participant is unable to complete the step within three attempts, mark it as incomplete and proceed to the next one

Task 7

Steps	Completed	Not Completed	Tentatives*	Time
Click on "Remove walls"				
Clicking on the wall between the living room and the kitchen				
(a warning appears)				
Click “accept”				
Clicking the "next" button in the bottom right corner to move to the next phase				
Observations: Participant's comments during task execution, behaviours, etc.				

*Record the number of actions taken until the correct action is completed. If the participant is unable to complete the step within three attempts, mark it as incomplete and proceed to the next one

Task 8

Steps	Completed	Not Completed	Tentatives*	Time
Click on the kitchen to select it				
Click on the U-shaped kitchen option to replace it				
Click on the bathroom suite to select it				
Click on the first option of the suite bathroom to replace it				
Click on the social bathroom to select it				
Click on the third option of the social bathroom to replace it				
Click the "next" button in the bottom right corner to move to the next stage				
Observations: Participant's comments during task execution, behaviours, etc.				

*Record the number of actions taken until the correct action is completed. If the participant is unable to complete the step within three attempts, mark it as incomplete and proceed to the next one

Task 9

Steps	Completed	Not Completed	Tentatives*	Time
Click on the “floor” button				
Click on the living room on the floorplan to select it				
Click on the library’s “Wooden floor” option				
Select the first option				
Observations: Participant's comments during task execution, behaviours, etc.				

*Record the number of actions taken until the correct action is completed. If the participant is unable to complete the step within three attempts, mark it as incomplete and proceed to the next one

Task 10

Steps	Completed	Not Completed	Tentatives*	Time
Click on the "finish" button in the bottom right corner to move on to the next phase				
(a warning appears)				
Click on “Overview”				
Click on “Submit”				
Clicar no botão Voltar para os meus projetos **OU** na cruz para tirar o quadro da frente	Click the “Back to My Projects” button **OR** the “X” to close the window			
Observations: Participant's comments during task execution, behaviours, etc.				

*Record the number of actions taken until the correct action is completed. If the participant is unable to complete the step within three attempts, mark it as incomplete and proceed to the next one