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Housing customization: envisioning an interface to support co-design processes

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Abstract

There are several studies showing that end-users' participation in the architectural design process of houses is critical to their satisfaction (e.g. Önder *et al*., 2010; Ammar *et al*., 2013). Housing that is not adjusted to inhabitants' needs leads to modification works (Davidson et al., 2007) that could be avoided if their design was defined from the beginning with their participation.

Digital technologies, such as 3D interactive visualization, benefit co-design processes by helping non-specialists better understand space and design possibilities (Salter et al., 2009; Schroth et al., 2006). However, the available literature shows that existing co-design digital tools were not developed based on potential users' requirements.

This paper aims to define the user requirements of a co-design tool for housing customization. Interviews were conducted to gather information on how participatory

processes occur in housing cooperatives and identify how potential users can collaborate in the design definition of their houses using a digital tool. The interviews were analyzed, and requirements were defined. This work contributes to the advancement of knowledge since the tool is defined based on requirements collected from potential end-users. By using a user-centered approach, the tool can contribute to more effective and informed collaboration.

Keywords: Customization. Housing. Digital tools. Co-design. User-centered design

1. Introduction

Meeting end-users' specific desires and needs is a challenge in architectural design. In the case of housing, especially mass housing, 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 and Hernàndez-Velasco, 2005). In these cases, houses are usually designed anonymously and following standards, which means that they are designed according to what the designer considers necessary. However, houses designed with the same spatial characteristics do not address the diversity of individual inhabitants' 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. By excluding inhabitants from the design process, the houses cause dissatisfaction (Önder et al., 2010), and they feel the need to make changes as soon as they move in or may even leave the house (Davidson et al., 2007). Therefore, for housing to be truly customized, end-users must participate in the design process from the initial stages in which crucial decisions are taken. However, Sabine Marschall (Marschall (1998) identifies the lack of understanding, skills and experience in architecture by the future

residents as problems related to difficulties in community participation. This situation makes it difficult to find common ground between designers and the end-users of the built environment. Brandt, Binder, and Sanders (2013) refer that “making” activities help non-specialists in architecture externalize their ideas and thoughts.

Besides, using certain digital technologies in participatory processes, such as 3D interactive visualization, allows residents to understand the space and design possibilities better (Faliu et al., 2018; Salter et al., 2009; Schroth et al., 2006). Moreover, Al Kodmany (2001) recommends using visualization tools with a high level of realism with laypeople.

Generative design computational systems, such as parametric design and shape grammars, can respond to the problem of housing customization, as they automatically allow exploring a wide range of solutions that respond to the diversity of inhabitants' needs. However, for these systems to be accessible to future residents, it is necessary to develop user-friendly, natural, and accessible interfaces. There is commercial software available for customized home design [e.g. IKEA Home and Kitchen Planner (Inter IKEA Systems B.V., 1999) and Sweet Home 3D (ETeks, 2006)] and prototypes based on generative design systems (e.g. Barcode Housing System (Madrazo et al., 2010), i_Prefab Home (Huang and Krawczyk, 2006) and ModRule (Lo et al., 2015). The problem we identify is that there is no evidence that these user interfaces were developed with potential end-users. Thus, a question remains: What are the requirements for a graphical user interface that supports inhabitants in the task of designing their houses collaboratively?

Our work is part of a broader research project focused on the user experience, whose goal is to define, prototype and test an interface of a digital tool aimed to support the co-design of customized housing. The purpose of this paper is to discuss the inhabitants’ experience in participatory design processes led by housing cooperatives and define the user requirements of such an interface that aims to improve this participation. We focus on housing cooperatives as an example of a multi-family housing context, which would benefit from the proposed interface. The contribution of this paper focuses on the fact

that a user-centered design methodology is adopted, in which the requirements are extracted from direct contact with potential users through interviews. In this way, the interface will be more likely to respond to the needs of its users.

After this introduction, in section 2, we discuss participatory design and collaborative design as we present a brief literature review on computational systems for housing customization. In section 3, we detail the methodology used to carry out the research and the interview protocol. In section 4, we describe the results of gathering the general needs of potential users of a digital tool that helps co-design customized housing. In section 5, we discuss the results and define user requirements. Finally, in section 6, we present the conclusions and suggest ways for future work.

2. Literature review

2.1. Participatory and collaborative processes

There is no unique definition of participation since this concept can be used in different areas and encompasses various levels of action. Authors such as Sherry Arnstein (1969) and Fredrik Wulz (1986) clarify this concept by translating it into scales that categorize end-users' influence on decision-making. Arnstein refers to participation as a political system of power distribution, which involves citizens with different levels of authority. From the architecture's point of view, Wulz defines participation as a method of including end-users' knowledge in the design process. According to this author, participation encompasses different levels of decision and interaction between the architect and the end-user.

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. Frost and Warren (Fröst and Warren, 2000) define participatory design as a way to obtain information from future users to create proposals that meet their needs. 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. Advocates of participatory design, such as Sanoff (2000, 2008), highlight benefits as, among many others, the feeling of ownership and community empowerment. On the other hand, 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, as they use technical language that the participants do not understand and thus 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. Mertens et al., (2023) agree with this point of view and further argue the need 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. Co-design, or collaborative design, refers to a collaboration in developing an architectural project from its initial phase. In this process, all those involved have the same level of authority and actively contribute to the discussion of ideas and the creation of solutions. It is also assumed that they contribute to the proposal's design (Stelzle and Noennig, 2019). However, the collaboration of inhabitants in the design customization of houses needs mechanisms to validate the design solutions. Digital tools are needed to achieve viable customized solutions at the mass-housing scale, as in traditional participatory processes, the validation process is costly and time-consuming (Khalili-Araghi and Kolarevic, 2018). According to Kwieciński (2023), in traditional participatory processes, correctness 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. The author argues 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 based on previously validated rules, thus responding to the diversity of users' needs without sacrificing the correctness of the solutions. Furthermore, although Al-Kodmany (2001) argues that traditional tools should be integrated with new technologies, the author also recognizes that the computerized ones enable the public to make more informed decisions (not only, but also) for their realistic visualization. Kwieciński also defends that generative design technologies should be integrated with user-friendly interfaces. Madrazo and his co-authors 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 dialog with a user in a language suited to the knowledge a user has at each stage of the process" (Madrazo et al., 2007).

2.2. Computational systems for housing customization

In the literature, we can find several computational systems specially developed for the design of customized housing. Different techniques to generate housing designs have been developed and evolved over time. In this paper, despite the technology used, we focus on its application to tools whose interfaces aim at helping inhabitants identify and represent their desires and needs when designing their future houses. In addition, these tools can help co-design processes. However, most are not available to be used in real scenarios (Raposo and Eloy, 2020).

Some shape grammars were created to generate housing designs within a specific language, such as Taiwanese traditional vernacular dwellings (Chiou and Krishnamurti, 1995), traditional Turkish houses (Çağdaş, 1996), vernacular Hayat houses (Colakoglu, 2005), Siza's houses at Malagueira (Duarte, 2005), Haiti Grammar (Benrós et al., 2011) and Favela da Rocinha (Dias et al., 2013). Other solutions were also developed to automatically obtain customized design solutions for renovating a specific apartment

type, such as Rabo-de-Bacalhau Transformation Grammar (Eloy, 2012) and Bourgeois House of Oporto (Coimbra and Romão, 2013).

There are also prototypes based on generative systems developed in research, which automatically generate housing solutions based on the input of end-user requirements (or which generate a part and allow the user to define the remaining). Examples are the Web-based User-oriented Tool for Universal Kitchen Design (Ma, 2002), A Platform for Consumer Driven Participative Design of Open (Source) Buildings (Mcleish, 2003), MALAG (Duarte and Correia, 2006), Barcode Housing System (Madrazo et al., 2010), i_Prefab Home (Huang and Krawczyk, 2007), ABC-based Customized Mass-Housing Generator (Benrós and Duarte, 2009) and Shaper-GA (Taborda et al., 2018).

There are also other rule-based systems, which do not start with the introduction of requirements but help users generate the design according to the decisions taken, step by step, during the housing definition [HouseMaker (MVRDV and Axis.fm, 2012), Group Forming (Ong et al., 2013), ModRule (Lo et al., 2015), A-Shaper (Santos et al., 2018) and Layout Generation (Veloso et al., 2018)]. However, despite the existence of these solutions, the literature does not report the testing and evaluation of the respective user interfaces.

In addition to the mentioned generative design tools, commercial software solutions are also available for free and under license payment. For example, the system Architechtures (SmartScapes Studio SL, 2019) generates multi-dwelling buildings and uses parametric design to generate different layouts by changing the parameters. Other commercial solutions allow users to design their houses from scratch according to their preferences and needs, such as IKEA Home and Kitchen Planner (Inter IKEA Systems B.V., 1999), Sweet Home 3D (ETeks, 2006) and Room Sketcher (RoomSketcherAS, n.d.). Unfortunately, the designs generated by these last couple of tools, intended to be used only by end-users, do not incorporate regulations or good architecture practices and, therefore, can generate solutions that are not, from that point of view, viable.

The tools mentioned are important contributions to customizing multi-housing projects in co-design processes. Some are based on generative design, and others are intended to be used by inhabitants through easy-to-use design tools without requiring technical knowledge. However, as mentioned, although there are several tool prototypes, these neither have interfaces specifically designed for end-users nor is there evidence that they have been developed with end-users, as far as the authors were able to find out in the literature.

3. Methodology

For the definition of a user interface for the co-design of customized housing, four phases were defined, namely: (1) collection of the general needs of the users; (2) definition of the system´s user requirements; (3) definition of the system's features and the user interface and (4) prototyping, testing and evaluating the system interface. This paper refers to phases 1 and 2. Phases 3 and 4 are ongoing research, and part of them is available at Raposo *et al*. (2023).

To collect the user's needs, the methodology was as follows: (1) definition of the interview model; (2) contact with potential interviewees; (3) carrying out the interviews and (4) systematization of results and definition of conclusions.

In total, 30 interviews were conducted, which were divided into 2 groups: 10 representatives of housing cooperatives and 20 inhabitants of these institutions. Neither the age nor the gender of respondents were controlled. Men and women between 25 and 77 years old were interviewed. The interviews were semi-structured with open-ended questions, as the goal was to explore the issues addressed and not limit the answers to predefined options. Recognizing that our interviewees may not possess technical expertise in architecture, we used straightforward language accessible to all. The formulated questions are listed as Appendix.

The interviews were mainly carried out online and were recorded (audio and image - with the explicit consent of the interviewee) through the Zoom platform and lasted between 60 and 90 min. In some cases, they were conducted in person, at the request of the interviewees, with audio recording. The research procedure was approved by the Instituto Universitário de Lisboa (ISCTE-IUL) Ethics Committee.

4. Collection of the general users' needs process

4.1. Interviews with housing cooperatives representatives

Interviews were done with representatives of housing cooperatives in Portugal that carried out processes in which their members were involved in the design definition of their houses at some stage. These interviews served to identify how these institutions operate concerning the process of designing, building and promoting housing and whether inhabitants participated or expressed their willingness to participate in the design process of their houses.

Four questions were made to the cooperatives representing the main topics discussed, such as the design phases in which inhabitants are involved, the way they participate and the cooperatives' awareness of inhabitants' interest in participating.

The representatives of the housing cooperatives were asked 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 1, 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 choosing.

In addition, the steps where 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 usually participate in the definition of

requirements 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 material samples at the cooperative's headquarters, or visits are made to the construction where there is a model apartment for inhabitants to see the applied materials.

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

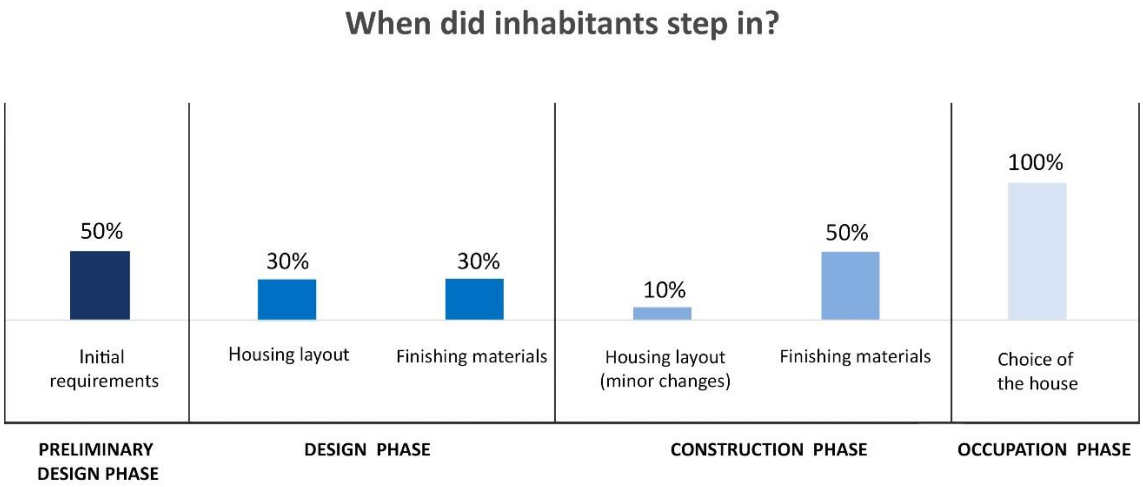

Figure 1. Moments in which inhabitants stepped in during the different design phases. Source: made by authors.

Regarding how the inhabitants participated, we asked cooperatives, “How did inhabitants participate? How was the participation session organized?”. Two cooperatives did not respond, as inhabitants did not participate. The remaining interviewees responded

according to three topics (Figure 2): (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 how inhabitants made their contributions (1), the cooperative representatives said they contributed orally and by filling out forms. The forms were used to collect information, define requirements and make choices of materials from the available options. 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. The representatives mentioned that inhabitants have some difficulty understanding the design through floorplans, but when the design is verbally explained, they could understand. Also, visiting the construction site helps gaining a better understanding of the space.

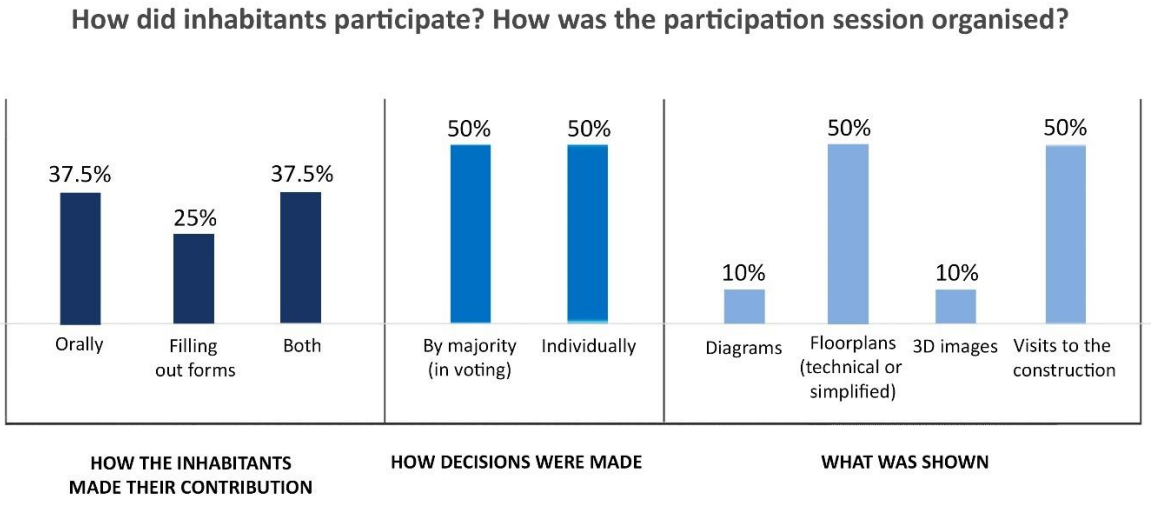

Figure 2. How cooperatives (n = =8) involved inhabitants according to three subjects: how inhabitants contributed, how decisions were made, and what was shown to the inhabitants Source: made by authors.

We asked cooperatives' representatives who triggers participation (Figure 3) and if inhabitants expressed a willingness to collaborate actively in the design definition phase (Figure 4). As shown in Figure 3, the participatory processes are top-down initiatives, mostly driven by cooperatives. The answers were given by eight cooperatives, as, in two of them, inhabitants did not participate. The representatives said that although inhabitants were motivated by the participation, there were shy people who 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.

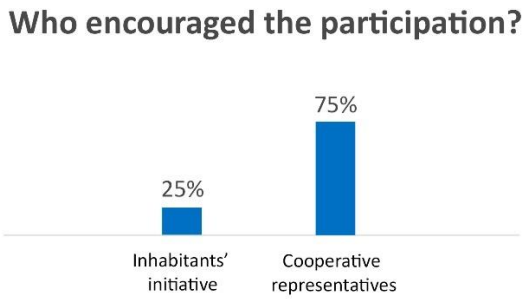

Figure 3. Initiative of having a participatory process. Source: made by authors.

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 (Figure 4). In some cases, people mobilized themselves to ask for changes; however, this happened in a small percentage.

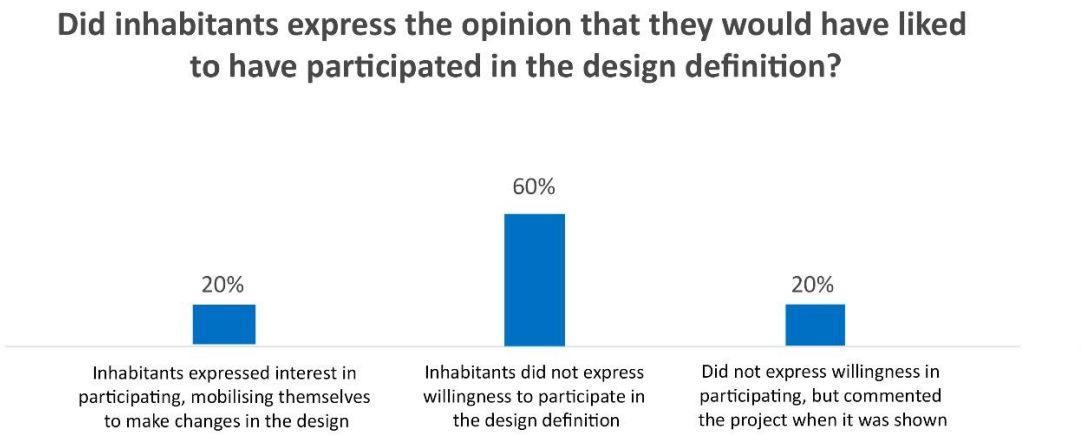

Figure 4. Cooperatives' perception of the inhabitants' willingness to participate in the design definition. Source: made by authors.

4.2. Interviews with inhabitants of housing cooperatives

The interviews with inhabitants were used to collect information about their perspectives on the process and the way they participated. Inhabitants that participated in the interview have been at least once confronted with the need to think about the project of their future house.

Five questions were made related to the participation process in which they were involved and to the participants' satisfaction with the outcome of the design and construction of their houses, as well as the process that took place. Such questions included what was shown, whether they had difficulties in understanding the design, what aspects they liked the most in the process and what they would change.

Regarding the open-ended question about what was shown to them to understand the project, from 20 respondents, only one (5%) answered that they saw nothing besides the final result as the built house. From the answers of the remaining respondents (Figure 5), we found that 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 are 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 less shown element.

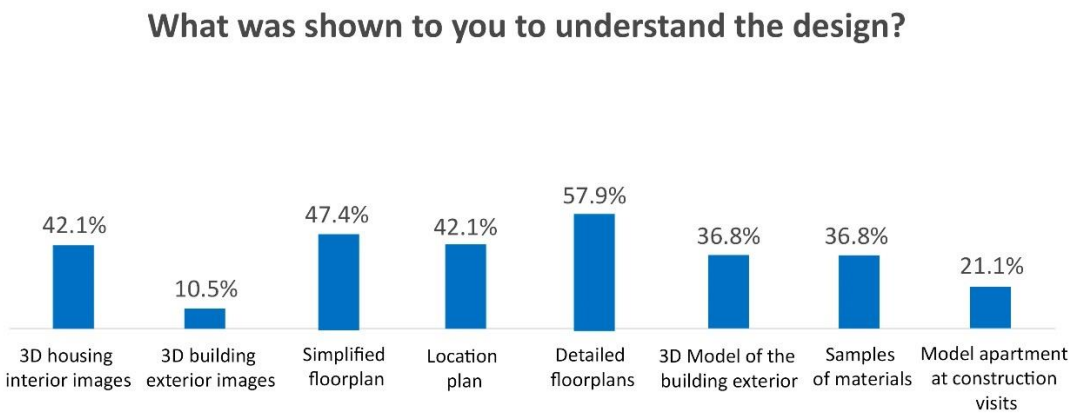

Figure 5. Elements shown to inhabitants (*n* = 19) to understand the project before the construction of houses is concluded. Source: made by authors.

To the question, "Did you have difficulties understanding what was shown?" one respondent did not respond. From the remaining (Figure 6), one person reported having difficulties 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 project. We also asked if they would have been able to understand the project 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.

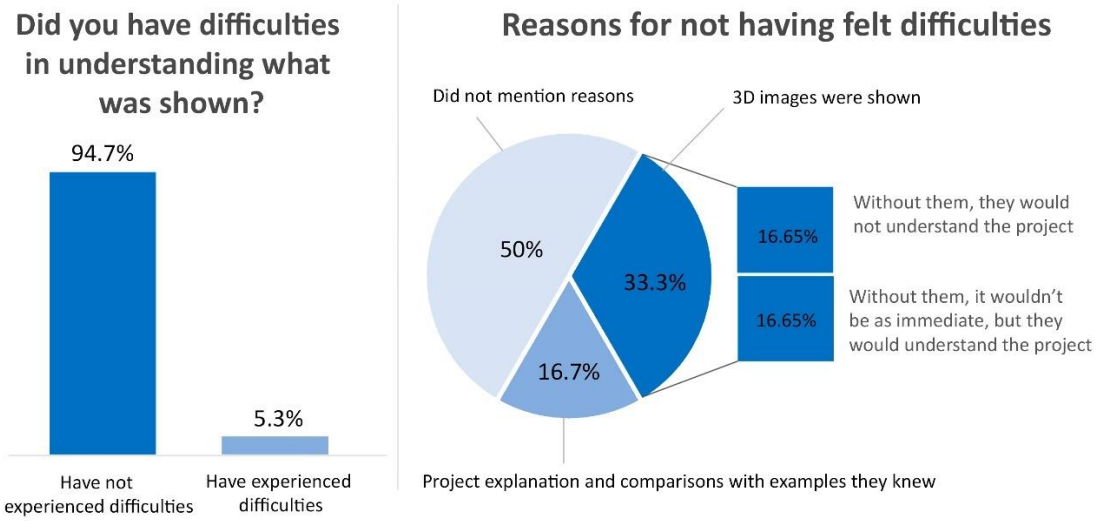

Figure 6. Inhabitants' answers (n = 19) regarding difficulties in understanding the project through what was shown to them. Source: made by authors.

Having contact with the design is what stands out regarding the aspect of the process they enjoyed the most (Figure 7). 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 customized house. Also, they said that seeing the design allowed them to visualize 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 at the moment the house was ready.

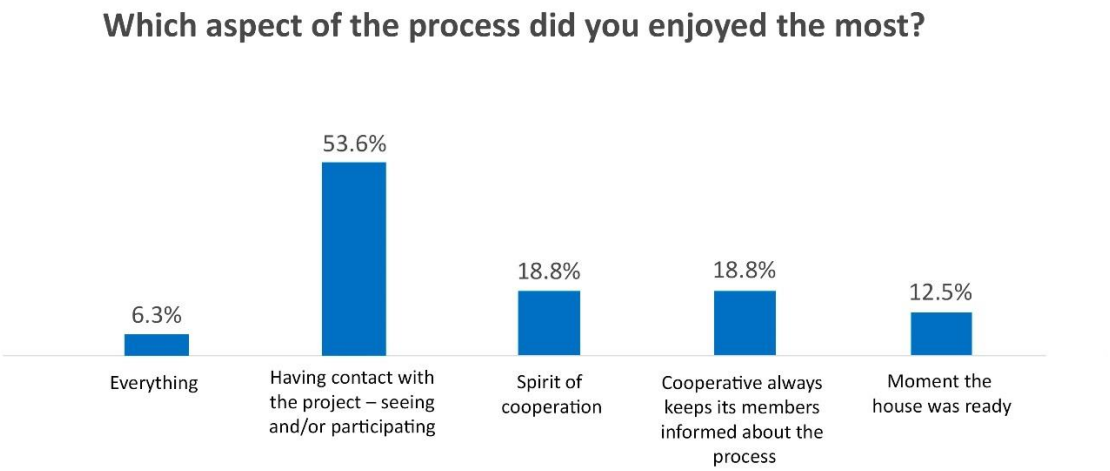

Figure 7. Aspects of the process that inhabitants enjoyed the most. Source: made by authors.

To the question, "What would you like to have been different in the process regarding your relationship with the designer?" two people (10%) did not answer. The responses of the remaining 18 interviewees were divided into 2 groups: those who had contacted one or more times with the designer and those who had no contact at all (Figure 8). Most of the inhabitants interviewed liked or would like to have contact with the designer to participate actively in the design definition. Only 22.2% had no contact with the designer and would not change this. Still, 11% of those who had contact with the designer would like to have been more frequent and effective. These people participated in the process but not in the design definition phase.

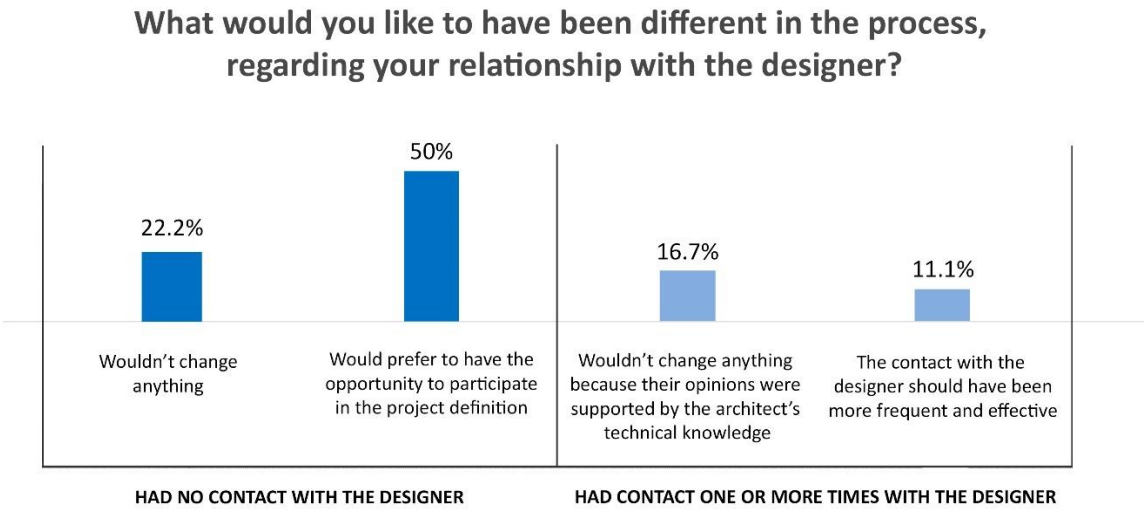

Figure 8. Inhabitants' opinion (n = 18) about the contact they had with the designer. Source: made by authors.

We asked the open 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?" (Figure 9), and 20% of respondents said they would not change anything. The remaining responses were given around two topics: how to participate and 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. Handle objects was the third most preferred. A minor percentage of inhabitants said they would like to participate by talking and writing, and 6.3% 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 the ones who referred that using technologies in participation was 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.

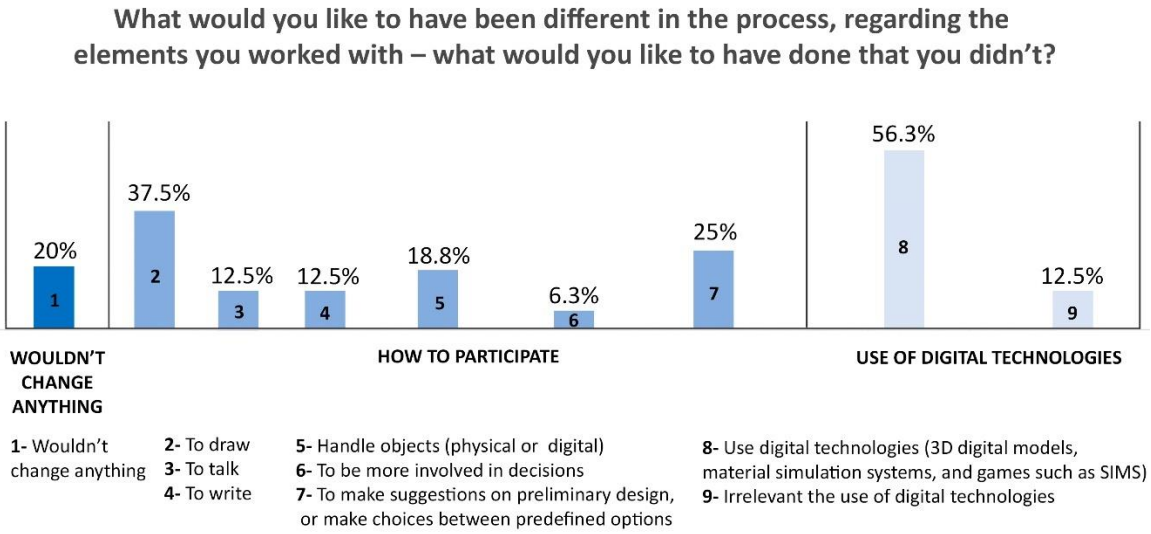

Figure 9. Ways in which inhabitants would have liked to participate. Source: made by authors.

5. Results discussion and user requirements definition

In this section, we discuss the results and present the insights taken from the interviews that will allow us to define the requirements for the tool we propose.

One relevant aspect mentioned is the phases of the design process in which inhabitants are involved. The results of the interviews show that, in the processes carried out by the housing cooperatives, the inhabitants are not usually involved in the design but rather in the initial stages (such as the definition of requirements) or later stages, where minor changes or choices that do not influence the overall layout of the dwellings (such as material selection) can be made.

We observed that housing cooperatives are the ones who trigger the participation of inhabitants and mention that inhabitants are not very interested in being involved in the design definition. 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. Data analysis shows that inhabitants have an interest in participating, but they do not always use this possibility when they have the opportunity. 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. Giving them the opportunity to collaborate on the design from the beginning overcomes this communication gap between members and representatives of the cooperatives. As such, inhabitants need to be better supported. As stated by Rachel 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 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 for non-specialists in architecture to read, as they may not have the same space perception as architects. Inhabitants reported no difficulties in understanding technical drawings if these are complemented with other less abstract ways of displaying the project (e.g. perspectives of spaces). In some cases, 3D images were shown, and this was mostly the reason why they did not feel difficulties in understanding the design. We argue that digital technologies play a crucial role here, as they allow the production of 3D digital models that can easily provide different perspectives. Accordingly, the literature shows that 3D interactive and immersive visualization allows non-specialists to better understand the space (Faliu et al., 2018; Salter et al., 2009).

Regarding the way to 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 collective 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. By collaborating on the design definition and production, inhabitants have a greater feeling of satisfaction and ownership regarding their houses (Ammar et al., 2013). Besides, making activities develop the inhabitant's creativity and allow them to express their needs and desires (Brandt et al., 2013).

According to the cooperatives' representatives, sometimes people do not know what they want, or they "just want a house". However, when a base project is shown, they are able to form a more informed opinion. Accordingly, 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 using digital technologies. Digital technologies can support participation by facilitating informed decision-making. As mentioned before, 3D digital models support the inhabitants' understanding of the space and, thus, making informed decisions. 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 (Tomić et al., 2023). This technology can generate a set of components that the user can combine to create customized solutions. Brandt et al. (2013) argue that 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 customize their houses without the need for technical knowledge, as it is guaranteed in the options presented to them. Thus, digital technologies' visualization and automation capabilities have the potential to improve co-design processes, helping non-specialists better understand design possibilities.

Based on these results, we identified key findings that allowed us to define the requirements for a housing co-design digital tool. Firstly, we found that, although

inhabitants are not involved in the design phase, they would like to participate more actively in the decisions about their living environments. However, they do not 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). Contreras-Espinosa *et al*. say that citizens are not aware of their relevance in developing their own cities and services.

Another finding was 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. 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 customization options, in supporting decision-making by non-designers during the co-design process. The authors emphasize toolkits as learning instruments, which are 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 customized solutions. Sanders et al. (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.

We also found that digital technologies bring benefits to participatory and collaborative processes such as, e.g. 3D visualization, which supports the perception of space by non-specialists in architecture. The results of the interviews show this tendency by the fact that the inhabitants reported that 3D visualization was the main reason for not having felt difficulties in understanding the designs shown to them. Additionally, such a finding is also supported by the literature (e.g. Salter *et al*. (2009); Schroth *et al*. (2006)), which demonstrates the positive impact that 3D interactive and immersive visualization has on the perception of space by non-experts. However, some authors state that technologies

can be a barrier due to factors such as lack of access and usability (Contreras-Espinosa *et al*., 2023). To overcome this barrier, we argue that accessible, easy-to-use interfaces must be developed, and thus, the requirements for such interface developments should be clear.

Given these findings, we consider that a digital tool that assists co-design in housing projects must comply with the following general requirements:

(1) *Direct contact with the design*: the tool should allow the user to make decisions about the housing design.

(2) *Provide a base design for the user to improve on*: the tool should support generative design that can be used to create viable design solutions that comply with the user's needs.

(3) *Choices through predefined options:* the tool 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 constraints and possibilities are provided by the architect.

(4) *Give immediate feedback*: the tool should allow the user to see the design while making decisions and see the result and consequences of their decisions in real-time.

(5) *Diverse perspectives:* In addition to the floorplans, the tool should allow a 3D visualization for a better understanding of the space and design possibilities.

6. Conclusion

The satisfaction of the inhabitants regarding their houses highly depends on their involvement in the definition of their living environments. However, participatory and co-design processes have some difficulties as the inhabitants' lack of technical knowledge

and lack of tools to allow them to express their needs and desires. These difficulties lead to a gap in communication between technicians and end-users.

Digital technologies support co-design processes as they can overcome these difficulties. Interactive 3D visualization and generative design help non-specialists in architecture better understand space and design possibilities. Using generative design for housing customization allows to automatically explore a wide range of design solutions that address the diversity of end-users. Also, integrating making activities gives inhabitants the means to collaborate and express themselves.

Unfortunately, the existing tools reported in the literature were not developed with the involvement of potential end-users. In this paper, we conducted interviews to gather useful information to define the requirements for a digital tool to improve the co-design of customized housing.

Our findings show that the inhabitants are willing to interact with the design and would like to have a digital tool to help them make decisions about their houses. They would also like to explore design possibilities by having a base design and making choices with predefined options. Finally, the type of visualization is paramount, and 3D visualization should be used to show the results of the decisions made during the design exploration, as the interviews showed the importance of 3D visualization for non-experts in architecture in understanding the designs shown to them.

A digital tool 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 participation. Collaborating on the design definition gives inhabitants a sense of satisfaction and ownership over the final outcome. Through realistic interactive visualization and generative design tools, users can explore design solutions and understand spatial configurations, empowering them to make informed decisions that align with their preferences and requirements. 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.

This paper contributes to knowledge of how a digital tool can support co-design processes. The innovation is based on the fact that the requirements of such a tool are extracted from direct contact with potential users. The features of a future user interface will be defined based on such user requirements. By using a user-centered approach, the interface can contribute to more effective and informed collaboration. However, although the tool is intended to be adaptable to any geographic context, there are limitations related to the type of project and cultural issues. The fact that the interviews were conducted with potential users in Portugal may condition the interface solution for a Portuguese audience.

Future work aims to develop a graphical user interface for a co-design tool centered on the user experience. The tool must be easy to use without the need for technical knowledge. For this reason, the tool must assist the inhabitant throughout the process to ensure that the dwelling design solutions generated are, on the one hand, in line with their needs and, on the other hand, the most viable solutions. The next step in our research will be to define, prototype and evaluate a graphical user interface for the co-design tool. As such, we aim to define visualization and interaction modes that respect the requirements for enabling the collaboration of the inhabitants with the architect in the definition of their houses in a simple and informed way.

Declaration of conflicting interests

The authors declare that there is no conflict of interest.

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Appendix

Housing cooperatives representatives Q1: *When did inhabitants step in?* Q2: *How did inhabitants participate? How was the participation session organized?* Q3: *Who encouraged participation?* Q4: *Did inhabitants express the opinion that they would have liked to have participated in the design definition?*
Inhabitants of Housing cooperatives Q1: *What was shown to you to understand the design?* Q2: *Did you have difficulties in understanding what was shown? Why?* Q3: *Which aspect of the process you enjoyed the most?* Q4: *What would you like to have been different in the process regarding your relationship with the designer?* Q5: *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?*
Source(s): Made by authors

Table A1: Questions formulated