International Association of Societies of Design Research Congress 2023
LIFE-CHANGING DESIGN
Politecnico di Milano
9-13 October 2023

Investigating the impact of digital fabrication on architecture design practice through a taxonomy

Silva, Daniela*[a]; Paio, Alexandra[a]

[a] DINÂMIA'CET-IUL, ISCTE-IUL, Lisbon, Portugal
* danielamoreirasilva@gmail.com

doi.org/10.21606/iasdr.2023.790

The integration of digital tools in architecture has transformed the design process, but the full potential of digital fabrication remains unexplored. This study examines the importance of digital fabrication in architecture design and suggests more suitable methods. Digital fabrication offers architects new ways to address complex tasks and innovate construction techniques, yet misconceptions persist about the role of digital tools in project-based research. The investigation analyses the impact of digital fabrication on architecture design and research methods, employing a taxonomy to categorize approaches and uncover connections within the design process. By studying select architecture firms, the research uncovers new modes of design thinking influenced by digital fabrication. These studios employ a combination of traditional methods and digital tools, fostering a symbiotic relationship that fuels the creative process. Ultimately, this study aims to contribute to the advancement of architecture design and research methodologies by revealing the potential of digital fabrication.

Keywords: digital fabrication; architecture design practice; research methodologies; taxonomy

1 Introduction

Technical change does not happen in a vacuum (Carpo, 2016). Digital technologies have been integrated into design and manufacturing, education, research, and architecture practices, giving architects far more control over the entire design process. The effects of this integration on practices in research-driven architecture design studios have to be studied. Only in this way it is possible to contribute to understanding the relevance of these tools in the process, highlighting the role of research to enhance current digital fabrication methods in architects' practice and also propose different methodologies more adapted to the architectural design process.

In this case, architectural research falls under applied research, designed for a specific application, transferring new knowledge into practice - a new type of design practice that is conceived to yield breakthrough results.

The computer is now a much less neutral element than it was during the Computer Aided Design (CAD) era when it was only used as a tool to replicate manual work of representation. Digital fabrication which is the focus of this study brings the computer into much more complex processes (Aish and Bredella 2017).

This article aims to interpret and debate the influence of design studio methodologies that are supported by digital fabrication. It is crucial to emphasise the use of these tools not for automation and alienation of architectural processes, but rather as a way of reclaiming the role of the architect as a key enabler for solving complex processes and broadening the architectural vocabulary. This is because digital fabrication is an integrated strategy in collaborative digital processes in architectural research and practice. This idea is supported by the studios that were the subject of this study.

The work of three architecture studios, that have adopted digital technology in their own practices and share a distinctive background in new techniques, is taken into consideration for this paper. Their work offers new design approaches to the practice of architecture as a result of the development of digital technology. This essay investigates the potential for new design thinking techniques supported by digital fabrication.

The study's findings lead to a taxonomy that envisions a new design-thinking process based on the approaches used by the participating architecture studios. This preliminary taxonomy introduces a new concept in which digital fabrication serves as both a support and an integrated part of the design process.

2 Background

In the early 90s, computed aided design was considered only as a tool to help the creative process, not yet seen as a tool with the potential to generate a creative process. However, Richard Buckminster Fuller demonstrated in the 1920s how technology's ability to accomplish "more with less" could lead to extraordinary performance leaps. It wasn't until the late 1990s and early 2000s that we started to see these tools enter the realm of architectural design. We came to see them as computational tools that help not only the creative process as considered until then, but also processes, protocols, and fabrication, thus allowing the architect to think with computation, or through computation. Digital fabrication is a method that has aroused the interest of architects and designers, as it opens the door to new possibilities for solving complex procedures and innovative approaches to construction.

However, there exist several misperceptions about the role and relevance of digital tools in project-based research methodologies in the studio context.

Digital fabrication is often seen as a way to automate the architectural process, which can lead to a feeling of alienation among architects. However, this does not have to be the case. Digital fabrication can actually be used as a way to return to the craftsmanship that was once so important to the profession. In fact, many architects are now using digital fabrication to create custom elements for their projects, which allows them to add a personal touch that would not be possible with traditional methods.

Architectural design is a process (Burry 2016). Digital design and fabrication empower designers to think and feel their way into a design and get feedback from it. The commonality among the architects

whose practises are discussed in this research is that they create prototypes of their designs (or components of them) in order to progress further in the design process.

With digital fabrication, form generation, and 3D printing, the way different professionals interact with architecture in the design and construction process can change. These technologies can provide an integrated design process, teach architects new skills and widen their vocabulary.

Although digital design and digital fabrication are two distinct components of a realisation process, they must be connected closely in order to reach their full potential.

Research projects, experiments, and the dedication of several architects and universities to digital fabrication have already created a new realm of possibilities for architectural expression. It seems appropriate to present an overview of the impacts this technology has had so far within the architecture practice. This article aims to reframe the possibilities that are made possible in architecture using additive manufacturing (commonly known as 3D printing). The process emerged in 1983 with stereolithography (SLA), which shoots an ultraviolet laser beam into a mass of photopolymer that then turns into solid plastic. Currently, there are many other processes and they evolve at a fast pace. The range of available materials has expanded beyond plastics to include metals, glass, clay and even nanocomposites.

Digital fabrication is taking over many industrial manufacturing processes, but its potential for construction has yet to be explored. It is still a new concept within the architecture community. However, architects and academics have quickly become interested in it, so it won't be long before it becomes commonplace in the design workflow. The introduction of digital fabrication in the architectural industry contributes to the significant shifts that necessitate the profession's reinvention.

3 Materials and methods

Since digital fabrication made it possible for new design mechanisms, the chosen methodology for this study encourages an overview of current office practices, leading to a re-evaluation of design-related theories.

For this purpose, the study used a methodology based on the examination of the output of three architecture studios to identify potential new design thinking techniques powered by digital fabrication.

Two of the selected offices are young studios and were chosen to participate in this study because of the way that their work was developed in a real-world setting that expanded combining the power of computational design and digital fabrication (studiorap, 2022) - a complementary relationship that drives the creative process.

HANNAH Office and Studio RAP (figure 1) are architecture studios established in a computerised environment and are dedicated to exploring digital design and fabrication. They both focus their work on the continuous process of combining the power of computational design with innovative digital fabrication methods.

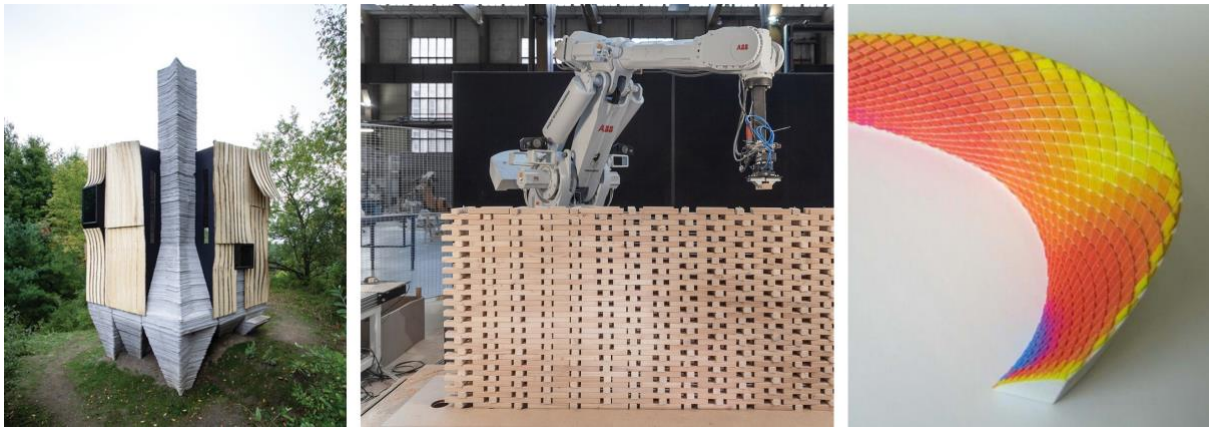

Figure 1. Left - Ashen Cabin, 2019, HANNAH Office; Middle – Circular Experience, 2019, Studio RAP; Right – a colour 3D print of a structure within the Duisburg Harbour Masterplan representing solar exposure throughout the day., 2007, Foster + Partner

HANNAH Office and Studio RAP (figure 1) are architecture studios established in a computerised environment and are dedicated to exploring digital design and fabrication. They both focus their work on the continuous process of combining the power of computational design with innovative digital fabrication methods.

HANNAH Office is an experimental design and research studio based in Ithaca, New York. Digital design and fabrication technologies are intrinsic in their work, facilitating fundamentally new material methods, tectonic articulations, environmental practices, technological affordances, and forms of construction. From furniture to urbanism, their projects aim to address the conflict between mechanical means and architectural aims by taking back control of the building processes that have an impact on how they can or possibly should create in the future (hannah-office, 2022).

Studio RAP is an architectural design company based in Rotterdam focused on combining the power of computational design with leading-edge digital fabrication methods. They develop innovative building processes inside their workshop in the Innovation Dock in Rotterdam. With the use of robotic fabrication, they challenge the traditional way of building and rethink the architectural profession. This leads to both expressive architecture and a rigorous, practical approach to problem-solving in the construction sector while trying to improve the way architects design, produce, manage and build their projects.

With digital fabrication, they were able to challenge the traditional way of building, rethink the architectural profession and address the digital in architecture as a radically contemporary building culture.

The architectural and construction industries are undergoing a transformation thanks to developments in computational design and digital production (fosterandpartners, 2022). Foster + Partners, is a world-renowned architectural firm based in London. The office is adopting computational design and digital fabrication to increase the material efficiency of building components and the construction methods used to create them. The Specialist Modelling Group (SMG) is a multidisciplinary team of designers that intersect computational design, building physics and research at Foster + Partners. This team has been leading the inquiry into efficient shapes and

materials and their application at various levels of design, from modelling all the way to construction inside the office.

Unlike the other two architecture studios presented in this research, which originated their practice within the digital environment, Foster + Partners started investing in 3D printers and rapid prototyping facilities in 2003, with the purpose to adapt the design methodologies used until then in their practice. Soon the office was able to take advantage of these tools that provided a faster way to create, what seemed like, a limitless number of prototypes, and computational design tools that could create almost infinite variations in shape and form further aided this process.

4 Taxonomy

The taxonomy design encompassed 2 stages: (1) analyses of the Design Thinking process (Gibbons, 2016), the Architectural Design Process Work Flow (hmh, 2022) along with the Digital Design and Fabrication Process (Hensel, 2016), and how they co-relate; (2) analyses a group of projects of each studio.

The first analysis is based on the Design Thinking Process proposed by Nielsen Norman Group, composed of 3 phases and 6 sub-phases (Gibbons, 2016), its relation with the Architectural Design Process Work Flow, by HMH Modern Architecture (hmh, 2022) and the Digital Design and Fabrication Process, proposed by Perkins + Will (Hensel, 2016). The original diagram of the Architectural Design Process Work Flow we complemented with the Operations and Maintenance stage, which we usually ascribe to the BIM construction process (ventures, 2022). As a result, the taxonomy was first developed in three levels associating the three ideas, where we can directly link the Design Thinking to the context of architectural practice and the Digital Fabrication Process (figure 2).

This preliminary taxonomy introduces a novel approach in which digital fabrication serves as both a support and an integral part of the design process.

The taxonomy adopts a radial structure, and the second analysis organizes projects from the selected offices on a timeline. Positioned within concentric circles, the projects are arranged by year, with more recent projects located farther from the center. Every project included in this classification represents a completed construction and is categorized based on the type of digital fabrication technique used, such as drones, 3D printing, or robotic arms. Furthermore, each project is aligned with the specific design phase in which the digital fabrication was applied, and a unique color has been assigned to each phase to provide a visual indication of the corresponding design stage.

The selection of projects presented in this taxonomy is deliberately focused on the built works of the architecture offices that form the core of our case studies. This approach offers several advantages: (1) Relevance: By focusing on built projects, we are able to analyse tangible outcomes where digital fabrication has been applied in practice, rather than theoretical or conceptual explorations. This ensures that the patterns identified are grounded in real-world applications and are reflective of current architectural practice. (2) Consistency: Drawing from the built projects of the selected architecture offices ensures a cohesive and consistent dataset. It allows for an apples-to-apples comparison across different firms and projects, enabling clearer insights into how digital fabrication is influencing design methods. (3) Limited Scope for a Targeted Analysis: While it is acknowledged that broadening the number of projects could provide additional insights, the chosen approach is aligned

with the paper's specific aim to investigate how digital fabrication is being implemented by leading design studios in their built works. Expanding the scope to include a larger number of projects could dilute this focus, and detract from the nuanced understanding we seek to achieve through this targeted analysis.

When analysing the data, it is evident that the studios view digital fabrication as a way to expand their research and enhance their craft's potential. The variety of projects included in the studies demonstrates their ability to operate at many scales, and through time, they have figured out how to make design profitable.

They have come to understand that by combining symbiotic techniques and pushing the boundaries of their practice, diversity is where they truly add value or contribute.

The case studies demonstrate a development process that depends equally on knowledge of physical characteristics and manufacturing procedures as it does on design intent, allowing more elements to be directly incorporated into the suggested outcome. Instead of merely replacing traditional sketching or modelling techniques, computation is directly integrated into the form-generation process. The techniques allow for the use of novel vocabularies that are not really feasible with conventional techniques. Through detailed modelling and testing of physical models, it would be difficult to attain the complexity in form variation associated with structural and material attributes. As a result, the project not only shows how differentiating building components may be to a great extent, but also how fabrication limitations and material qualities can be included into form generation.

The case studies show potentials that could be improved upon and modified for use in further projects. The possibilities should become clear when more realized instances of these kinds of architectural projects appear. We can already observe a number of outstanding projects, like the House of Cores (2022) and Ashen Cabin (2019) by the Hannah Office (figure 3), and the SkilledIn Office (2016) by the Studio RAP (figure 4), that clearly rely on digital manufacturing. However, a more comprehensive and integrated approach will enable the concepts to have a greater overall influence on the built environment.

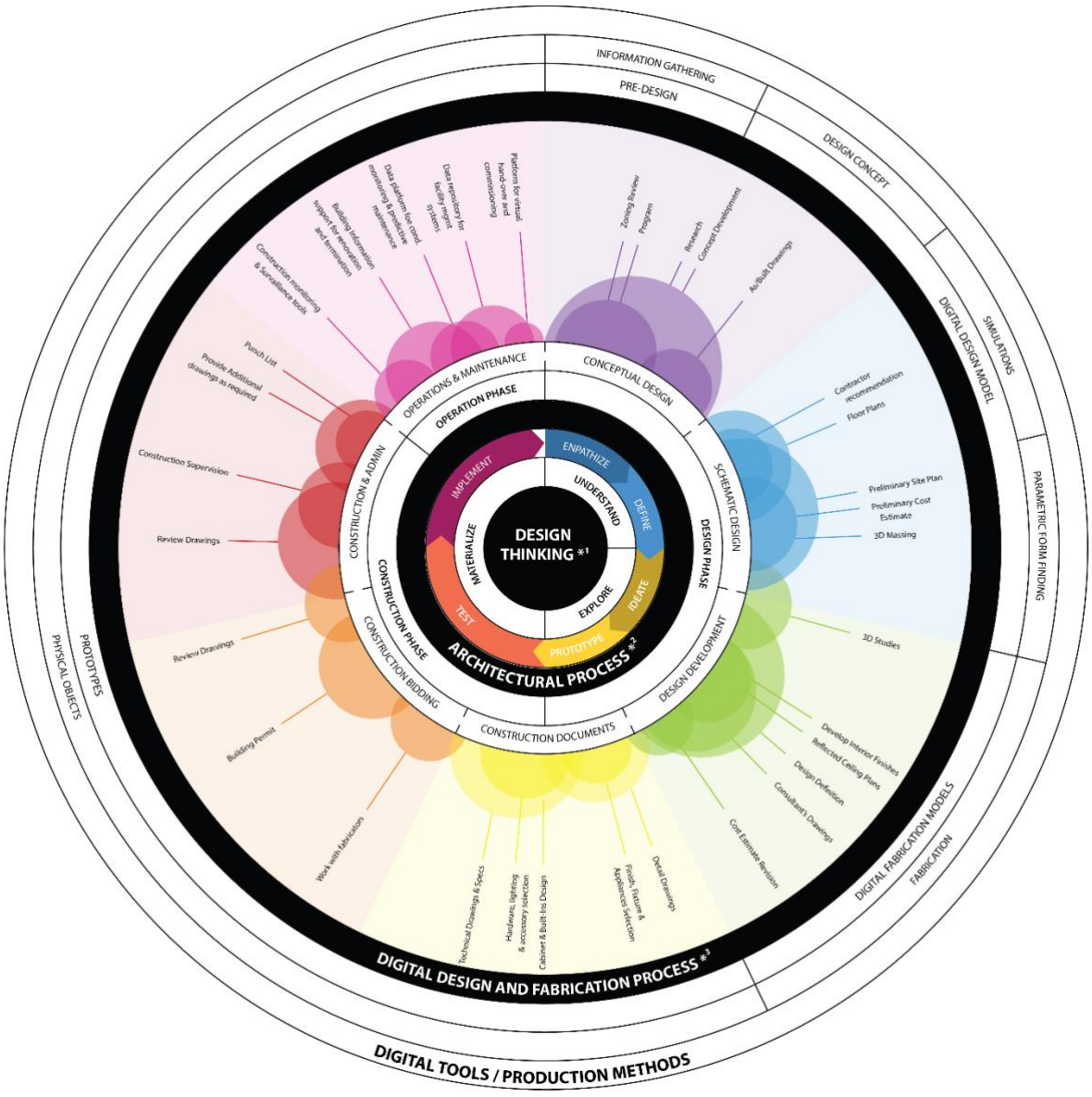

Figure 2. Preliminary taxonomy relating Design Thinking, the Design Process Work Flow and Digital Design and Fabrication Process

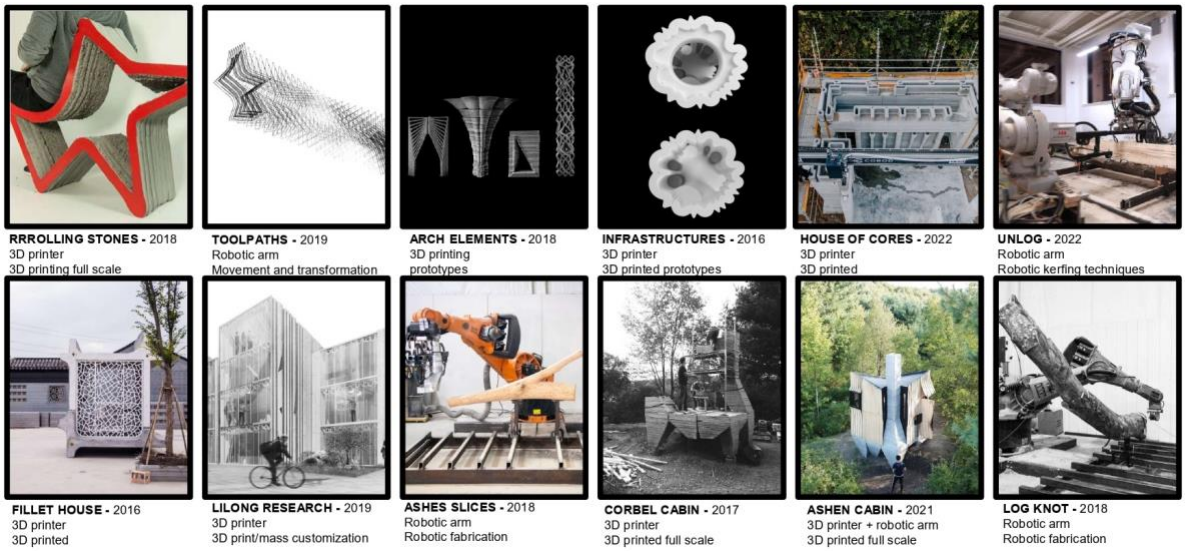

Figure 3. Selected built projects, ranging from 2016 to 2022, HANNAH Office

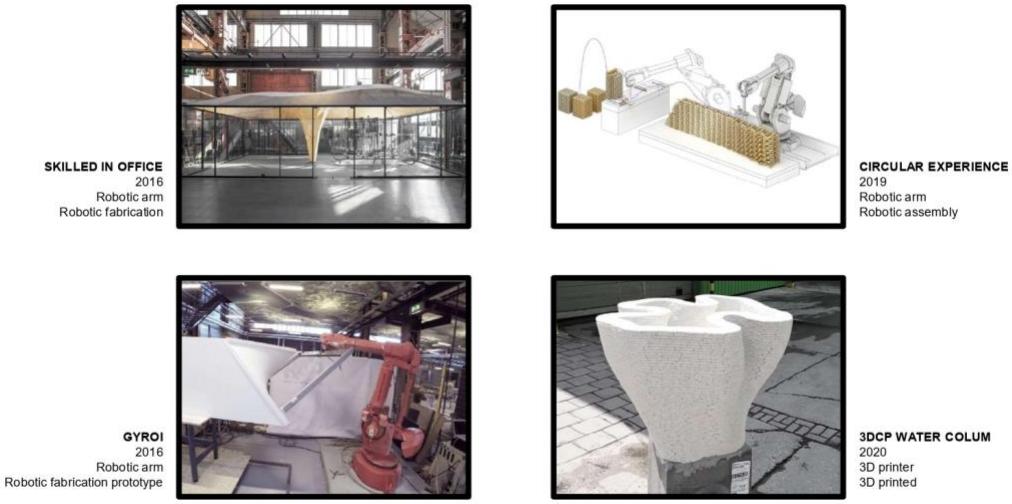

Figure 4. Selected built projects, ranging from 2016 to 2020, Studio RAP

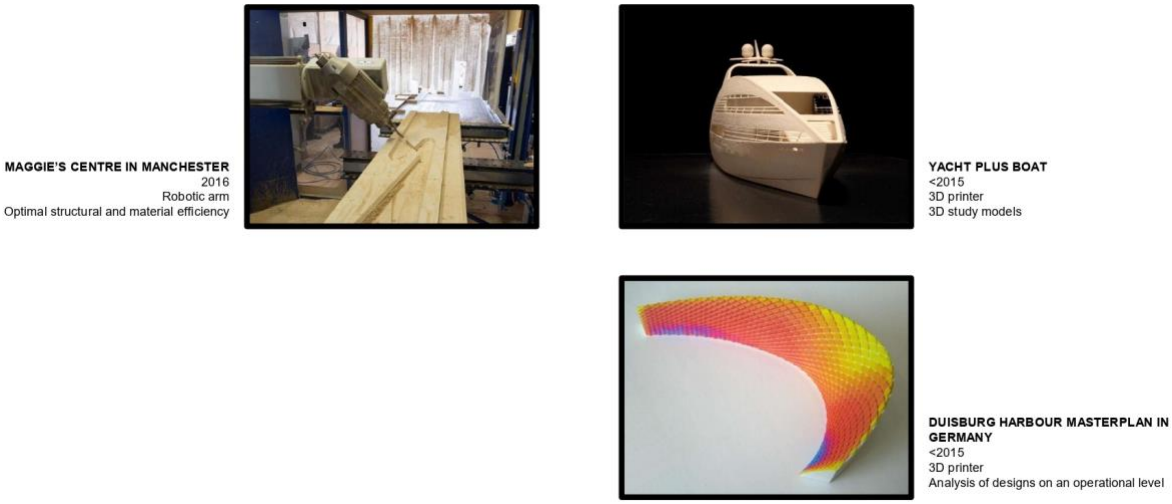

Figure 5. Selected projects, previous to 2016, Foster + Partner

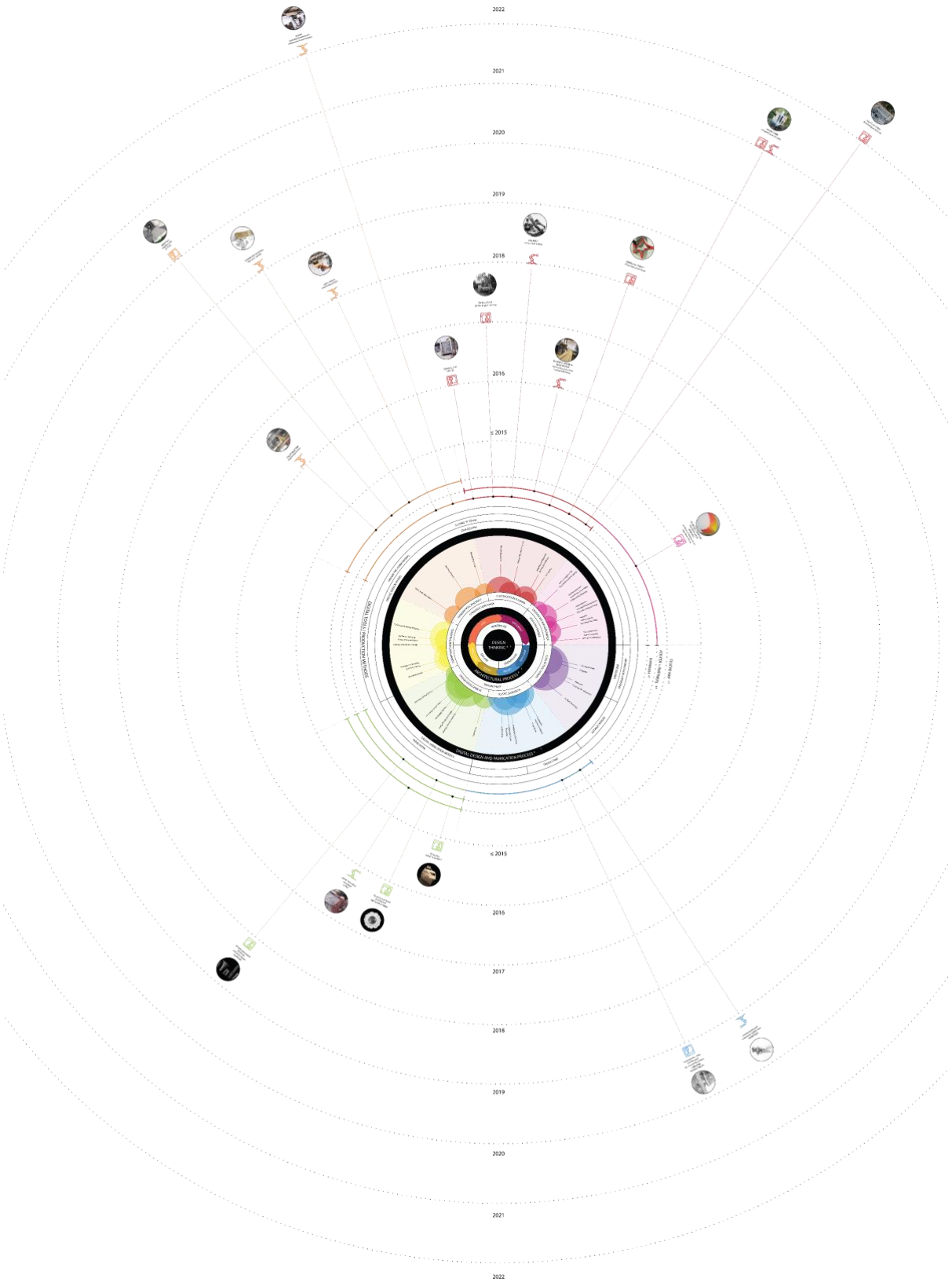

Figure 6. Preliminary taxonomy relating HANNAH Office, Studio RAP, and Foster + Partners group of projects

5 Discussion

The taxonomy produced (figure 6) supports and understands the main investigation's hypothesis that digital fabrication is not only a tool but rather an integrated approach in collaborative digital processes that can improve communication throughout the design process.

By analysing and evaluating the work developed by these three studios, we can relate and understand how three independent offices have used digital technologies to establish their particular modes of operation and thought processes.

There is no denying that the industry is embracing new approaches while extending manufacturing customs. Their work makes it obvious that digital fabrication is a technology that is used to support the entire process along the design thinking practice, not only as a tool to manufacture the finished product.

In this essay, we claim that digital fabrication may enhance design thinking in the architectural studio, fostering a deeper comprehension of these processes among architects. To enhance the conventional workflows that design studios are currently accustomed to, digital fabrication is coming together; when properly applied, this technology simply evolves current workflows rather than necessarily replacing the present tools.

This article is a part of a study that examines the architectural design process and is based on the idea that there are additional design methodologies that should be included in the study of design techniques. It envisions digital fabrication as a strategy that is integrated into collaborative digital processes and can improve communication throughout the design methods, rather than only as a tool. It outlines the evolution of design methodologies to allow users to have a better understanding of the approach for design projects while keeping in mind that each one is a product of its time.

The development of intricate technological and environmental issues pushes professionals to look for new forms of interchange and collaboration that intentionally transcend and shatter conventional discipline boundaries. In addition to reinventing how products are developed and made, this collective approach to using technology is also radically altering the culture, politics, and economics of the creative industries as a whole.

If the first robotic era – the age of industrial automation – greatly increased our physical output, the second robotic era will undoubtedly stand out as a driver of creative capacity. The time is right for fusing technology with creativity and materialization, stimulating original scientific research and opening up new horizons.

Based on the work produced by HANNAH Office (figure 3), Studio RAP (figure 4) and Foster + Partners (figure 5), it is clear that the emergence of computing and fabrication has already made it possible for design and digital fabrication to interact, enabling the coordination of production from file to factory to site.

The preliminary taxonomy developed in the scope of this research allows us to understand the influence of digital fabrication within the design process in architectural practice while questioning the basis of education and the conceptualization of architecture.

6 Conclusion

This article aims to explore how design studios' methods driven by digital fabrication are challenging architectural practice. Design thinking methodologies combined with digital fabrication have emerged as a key technological and design issue in contemporary research and design, as seen in various academic studies and practical applications (Aksamija, 2016).

Integrating digital fabrication into design thinking contexts is by no means a straightforward process. However, as revealed through the analysis of built projects from specific architecture offices (refer to taxonomy section), digital fabrication, when thoughtfully incorporated into the design studio's workflow, can enhance design thinking and significantly improve the material efficiency of building elements and the methods with which they are constructed. This improvement in material efficiency is evidenced by the reduced waste and optimized use of materials in our examined projects (Beorkrem, 2012).

Design thinking inherently supports studio work, where failure, iterative procedures, and ongoing reflections on the materials used in manufacturing are essential components of the process. Through our observational research, this study laid out a course for further investigation into how design thinking may be thoughtfully incorporated into reflective and creative digital fabrication processes within the design studio.

The interplay between design thinking and digital fabrication is a rich field of study with practical implications for architectural practice. The insights gained from this research, grounded in both theory and real-world application, contribute to a deeper understanding of this relationship and point toward exciting avenues for future exploration and innovation.

References

Aish, R. & Bredella, N. (2017). The evolution of architectural computing: from Building Modeling to Design Computation. arq: Architectural Research Quarterly. 21 (1), 65-73. https://doi.org/10.1017/S1359135517000185.

Aksamija, A. (2016). Integrating Innovation in Architecture. Wiley.

Beorkrem, C. (2012). Material Strategies in Digital Fabrication. Routledge.

Burry, J., Sabin, J., Sheil, B. & Skavara, M. (2020). Fabricate 2020 - Making Resilient Architecture. UCL Press.

Burry, M. & Burry, J. (2016). Prototyping for Architects. Thames and Hudson.

Carpo, M. (2017). The Second Digital Turn. Design Beyond Intelligence. The MIT Press.

Corser, R. (2010). Fabricating Architecture. Selected Readings in Digital Design and Manufacturing. Princeton Architectural Press.

Frazer, J. (1995). An Evolutionary Architecture. Architectural Association.

Gibbons, S. (2016, July 31). Design Thinking 101. Retrieved October 16, 2022, from https://www.nngroup.com/articles/design-thinking/

Hensel, M. & Nilsson, F. (2016). The Changing Shape of Practice: Integrating Research and Design in Architecture. Routledge.

HMH Architecture + Interiors (2014, December 18). Design Phases. Retrieved October 16, 2022, from https://hmhai.com/faq-items/design-phases/.

Iwamoto, L. (2009). Digital Fabrications: Architectural and Material Techniques. Princeton Architectural Press.

Kieran, S. & Timberlake, J. (2004). Refabricating Architecture: How Manufacturing Methodologies are Poised to Transform Building Construction. McGraw-Hill.
Kolarevic, B. (2003). Architecture in the Digital Age: Design and Manufacturing. Spon Press.
Kudless, A., Pigram, D., & Harding, J. (2012). Fabricate: Making Digital Architecture. Riverside Architectural Press.
Larsen, N. M. (2016). Digital Fabrication in Tomorrow's Architecture, OPEN ROOM publication series no. 3. Arkitektskolens Forlag.
Martindale, K. (2022). Research for Architectural Practice. Routledge.
McCullough, M. (1998). Abstracting Craft: The Practiced Digital Hand. The MIT Press.
Menges, A. & Ahlquist, S. (2011). Computational Design Thinking. John Wiley & Sons.
Nilsson, F. & Hensel, M. (2016). The Changing Shape of Practice. Integrating research and design in architecture. Routledge.
Oxman, N. (2007). Digital craft: Fabrication-based design in the age of digital production. In: Workshop Proceedings for Ubicomp 2007: International Conference on Ubiquitous Computing (pp. 534–538). Innsbruck.
Roudavski, S. (2011). Selective Jamming: Digital Architectural Design in Foundation Courses. International Journal of Architectural Computing, 9(4), 437-461.
Schodek, D. L., Bechthold, M., Griggs, K., Kao, K., & Steinberg, M. (2004). Digital Design and Manufacturing: CAD/CAM Applications in Architecture and Design. John Wiley & Sons.
Ventures, C. (2021, August 9). Discover how BIM is implemented in each step of the construction value chain. Retrieved October 16, 2022, from https://www.cemexventures.com/discover-how-bim-is-implemented-in-each-phase-of-the-construction-industry/
Wilkinson, S. & Mason, J. (2020, April 27). A Journey to Digital Manufacture. Retrieved October 19, 2022, from https://www.fosterandpartners.com/plus-journal/a-journey-to-digital-manufacture/
Yuan, P., Manges, A. & Leach, N. (2017). Digital Fabrication. Tongji University Press.
[1] https://www.hannah-office.org/
[2] https://studiorap.nl/