OPTIMISATION OF A DESIGN-TO-FABRICATION FRAMEWORK FOR INDIVIDUALISED HOMELESS HOUSING DESIGN IN MELBOURNE, AUSTRALIA

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ABSTRACT

Digital design tools and technologies offer new opportunities for designers to generate a diverse range of design solutions. Previous research have discussed the multifaceted use of such technologies for 1) rapid visualisations, 2) generating design options, and 3) predicting design solutions. However, such research have focused more on simplifying design for fabrication and less on the integration of individual needs in design processes. This research adopts a human-centric design approach to merge user-to-design and design-to-fabrication processes. Through a scoping review on homelessness, design, and fabrication, we contribute a user-design-fabrication framework devised for the specific and dynamic needs of homeless individuals living in Melbourne, Australia. Our findings suggests that to optimise digital design processes for individuals with specific and dynamic needs, designers need to understand, translate, and embed the social, design, and fabrication complexities of a design problem. Future research should therefore test the real-world application of our user-design-fabrication framework and evaluate the impact of such digital design processes, for the provision of more individualised homeless housing design solutions.

Keywords: Optimisation, Design process, User centred design, Design-to-fabrication, Homeless housing

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1 INTRODUCTION

Designs for our socially complex world have seen a rise in demand for more affordable housing that better meet the needs of its dynamic population. This research extends this notion towards Australia's homeless housing problem, where housing accommodations are yet to be constructed based on individual needs, circumstances, and life's ever-changing experiences. For this reason, there has been a recent shift in Australia's homeless housing problem from a shortage of housing supply to a problem of housing for individuals with specific and dynamic needs. Importantly, these heterogeneous changes in our societies have introduced a greater challenge in architectural and construction industries to respond to the supply and demand of more individualised housing design solutions.

To address such housing crises, previous research have argued the need for architects to investigate novel housing design solutions through more purposeful explorations of modern design tools and technologies (Mahdi, 2021). In fact, previous research have also forecasted the likelihood of future design processes to adopt computer-aided design (CAD) and computer-aided manufacturing (CAM) for more rapid and efficient responses to growing urban needs (Beirao et al., 2018; Daher et al., 2015). However, despite these recommendations, current evidence to assist the design of housing for niche populations remain limited and understudied (Petersen, 2015).

Hence, this research contributes to the field through an exploration of a novel housing design solution that responds to the specific and dynamic needs of individuals. Specifically, this research investigates cases of 1) homeless experiences and 2) design-to-fabrication tools and technologies, to 3) contribute a human-centric design-to-fabrication framework. Such framework was devised for the design of housing catered to homeless individuals living in Melbourne, Australia. Based on the new framework, this research describes the implications for future researchers and designers seeking to address such homeless housing crises to further examine the role of designers as active decision makers in digital design processes, to ultimately optimise homeless housing design solutions through a more human-centric design approach.

2 BACKGROUND

Today, housing design solutions must look further into digital design tools and technologies to better integrate changing contextual needs into its design processes. More recently, research by Pantazis and Gerber (2019) and Freire et al. (2021) have shown that more purposeful design solutions emerged when changes in needs were identified at different stages of a design-to-fabrication process. Specifically, their research demonstrated how the input of contextual information in the beginning of the design process (Pantazis and Gerber, 2019) and how the recognition of changing contextual needs in the latter stages of the fabrication process (Freire et al., 2021) allowed for improved adaptability of design solutions, responding to current contextual and environmental challenges. Beforehand, housing design solutions had adopted digital design tools and technologies for more rapid and generative design processes. Previous research conducted by Kocaturk (2007), Marion et al. (2012), and Stals et al. (2018) had explored the multidisciplinary use of digital design to efficiently generate and visualise ideas, predict design solutions, and produce construction documentations for architecture, engineering, and construction (AEC) industries, responding to our past needs for a rapid supply of housing.

These studies have not only shown the dynamic changes that have occurred in our societies, but most importantly, these studies have shown evidence of designers and researchers developing, innovating, and evolving digital design processes to address timely needs. Such actions may be the by-product of a desire to forecast the impact of digital design tools and technologies used in practices today (Wang et al., 2020), especially for the popularisation such digital design processes to be adopted in architectural and construction industries (Li and Zhao, 2016). In fact, both Siddika et al. (2019) and Pan et al. (2021) have argued that apart from Singapore and China, governments are yet to set a national building code for digitalisation in AEC for local applications. In turn, the absence of such popularisation and building standards limit the opportunities for digitalisation of design processes to assist in the design of housing for individuals with specific and dynamic needs.

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Therefore, designers and researchers attempting to address the homeless housing crises should examine a human-centric design approach to leverage the capabilities of digital design tools and technologies for the specific and dynamic needs of individuals. Hence, our research aims to:

1. Understand the dynamic needs of homeless individuals in Melbourne, Australia, to
2. Optimise digital design tools and technologies accordingly, and
3. Create a holistic digital design process to address Australia's homeless housing problem.

3 THEORETICAL BACKGROUND

For such a multidisciplinary research study, we looked to different disciplines of knowledge that have discussed key theories that underpin the varying approaches to homelessness, housing design, and fabrication solutions. First, this research takes a human-centric approach to examine *Dynamic Homelessness* (Chamberlain et al., 2015), which is concerned with the social challenges of homelessness at an individual level. Next, this research takes a design approach to examine the application of *Architectural Complexities* (Stals et al., 2018; Pantazis and Gerber, 2019) for sociological and digital design contexts. Lastly, this research references *Technological Trajectories and lock-in* (Wang et al., 2020), to investigate how emerging digital design tools and technologies in AEC are used to optimise different design solutions for different needs.

3.1 Dynamic homelessness

To study Australia's homeless housing problem human-centrically, this research adopts Chamberlain's theory of *Dynamic Homelessness*, which draws references from an individual's transitional cycle coming into and out of homelessness over time (Chamberlain et al., 2015). This theory was discussed more explicitly with reference to Gidden's *Structuration theory* of entries into and out of homelessness (Giddens, 1984). Importantly, these theories supports our research as it encompasses both objective and subjective views of homelessness based on a cultural definition, minimum community standards, and person-oriented approach to homelessness (Chamberlain and Mackenzie, 1992; Chamberlain et al., 2015). The subjectivist person-oriented approach being concerned with the individual meaning of home as a place for social and cultural expression, engagement, and belonging to construct individual ways of being (Chamberlain et al., 2015).

3.2 Architectural complexities

From a design perspective, digital design processes in practice should therefore accommodate for the social complexities of dynamic homelessness. This research builds on the theory of *Architectural Complexities* proposed by Stals et al. (2018) and Pantazis and Gerber (2019) and applies it to sociological and digital design solutions. The theory supports this research through a discussion of how designers have and will continue to explore CAD through the domains of 1) complexity of design problems (i.e., homelessness), 2) complexity of design processes (i.e., digital design-to-fabrication), and 3) complexity of construction and building systems (i.e., housing design and fabrication solutions) (Stals et al., 2018; Pantazis and Gerber, 2019). Such domains are applicable in AEC and reflect the varying complexities that may arise from the integration of specific and dynamic needs of individuals into a human-centric design-to-fabrication process.

3.3 Technological trajectory and lock-in

As we transition from Industry 4.0 to Industry 5.0, this research emphasises the importance of reflecting and acknowledging the *Technological Trajectories and Lock-in* (Wang et al., 2020) that have occurred thus far. This theory proposed by Wang et al. (2020) had discussed the patterns of change in digital design technologies (i.e., the trajectory) that has led to the emergence and introduction of industry standards (i.e., the lock-in). Importantly, such theory has acknowledged the development and innovation of fabrication technologies as a cyclic process of merging new and existing knowledge from various disciplines, leading to greater social impact (Wang et al., 2020).

While the above theories are often discussed within the confinements of their own disciplines, this research argues that such theories on homelessness, design, and fabrication disciplines of knowledge, are comparable. For instance, both discussions of *Architectural Complexities* (Stals et al., 2018; Pantazis and

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Gerber, 2019) and *Technological Trajectories and lock-in* (Wang et al., 2020) have acknowledged the challenges and changes in design and fabrication solutions for greater social value. This is also reflective of *Dynamic Homelessness* (Chamberlain et al., 2015), where several attempts to re-approach and re-define homelessness were prompted by the increasing complexities of the homeless demographic. Thus, this research attempts to provide a framework and examine Australia's homeless housing problem through the research question, *How can digital design processes be optimised for specific and dynamic needs of homeless individuals in Australia?*, which we broke down further into the following sub-questions:

RQ1 What are the social complexities of dynamic homelessness in Melbourne, Australia?
RQ2 What are the design complexities that emerge from such a design problem?
RQ3 How can digital design tools and technologies address such design complexities?

4 METHOD

As part of the first phase of our research project, we conducted a scoping review on two different disciplines of knowledge, homelessness and digital design, to address the research questions. Specifically, this research first conducted a literature review as a method of extracting new data from a set of individual case studies (Hannington and Martin, 2012) pertaining to homelessness, design, and fabrication. For this review, we approached data on homelessness from a research for design perspective (Frayling, 1994), to translate social complexities into design complexities. Data on digital design were then approached from a research into design perspective (Frayling, 1994), to address design complexities with digital design solutions. Such research uncovered the hidden themes that underpinned the two disciplines of knowledge, enabling the conceptualisation and optimisation of a design-to-fabrication process for the specific and dynamic needs of homeless individuals.

Data collected for the literature review include a set of qualitative case studies and photobooks accessed through government and university database. Specifically, 14 homelessness case studies (inclusive of 3 photo studies) were sourced to conduct research for design and a further 20 digital design case studies were then sourced for research into design. We then developed a set of two synthesis matrix to analyse and organise the data thematically.

The first synthesis matrix was used to examine individual case and photo studies of homelessness in Melbourne, Australia. The coding system expanded on Giddens *Structuration Theory* (Giddens, 1984) and acknowledges the spectrum of structural and individual factors impacting an individual's pathway into and out of homelessness. Structural factors referring to different housing conditions and individual factors referring to different living circumstances. For housing design purposes, this research defined the factors of an individual's pathway into homelessness as the structural factor of housing history and the individual factor of cause of entry. Additionally, this research defined the factors of an individual's exit out of homelessness as the structural factor of housing expectations and the individual factor of aspiration for exit (see Table 1).

Table 1. Coding system used to examine homeless case studies.

Cycle of homelessness	Structural factors	Individual factors
Pathway into homelessness An Individual's entry into "the cultural definition of homelessness"	Housing history Squats Boarding houses Supported accommodation	Causes of entry Eviction Family conflict Financial instability
Pathway out of homelessness An individual's exit out of "the cultural definition of homelessness"	Housing expectations Garden Two-bed unit Independent housing	Aspirations for exit Ownership Finding family Social relations

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The second synthesis matrix was used to examine digital design tools and technologies human-centrically. To do so, the coding system was divided into two categories. First, the case studies were organised into its respective disciplines of knowledge and the type of digital design tool and technology adopted. Second, each case was then analysed based on its impact on either design or societal practices (see Table 2).

Table 2. Coding system used to examine digital design case studies.

Category	Sub-categories	
Technology The adopted digital design tool and technology.	Discipline Architecture Civil engineering Construction	Project Building Information Modelling (BIM) for noise barrier tunnels.
Impact (if any) The real-world implications of said digital design tools and technologies.	Design practice Advanced design visualisation Optimise design performance. Improved design accuracy	Societal practice Realizing sustainable systems Optimising healthcare design Automating housing design

5 FINDINGS

In the following section, we describe our findings on the social complexities of homelessness in Melbourne, Australia, to address RQ1. We continue by providing our analysis on the design problems that have emerged as a product of such social complexities, that were then translated into a set of design complexities, to address RQ2. We then conclude our findings and describe the digital design tools and technologies that accommodate for such design complexities, to address RQ3.

5.1 The social complexities of dynamic homelessness in Melbourne, Australia

Dynamic Homelessness in Melbourne, Australia is highly individualised, where cases often presented opposite experiences of homelessness within similar demographics of youth, adult, and family homelessness (see Figure 1). Specifically, we found that polarities exist in the way individual factors were described and how such individual factors were ultimately shaped by the structural factors of their homeless experiences. We elaborate on these polarities in the following paragraphs and with reference to the engaged personas outlined in Figure 1.

Tangibility of factors and needs: Homeless individuals often describe their needs in two distinct categories, tangible and intangible needs. Individuals with tangible needs referred to structural factors such as housing accommodation, community, and occupation. These needs were less likely to change as the image of home was physically more present. For example, persona 1 wanted to live in multiple homes due to their experience living in transitional housing programs. On the other hand, individuals with intangible needs often referred to individual factors such as relationship, sense of belonging, and independence. These needs were bound to change in the latter as their image of home was more conceptual. For example, persona 2 wanted to start a family, where changes in household dynamics are likely to change pre-existing needs. **Aspirational differences:** A individual's exit out of homelessness were often described as either socially or personally motivated. Individuals who were socially motivated wanted to find, re-establish, and reunite with friends, families, and other forms of companionships previously lost. Individuals who were personally motivated wanted to have employment and a greater sense of ownership and independence. This is the case of personas 2 and 3, where one was socially motivated to start a family, and the other was personally motivated to make their own home. **Housing conditionalities:** Depending on their housing history, homeless individuals fall into three general groups. There are those who prefer a more public life after living in isolation (persona 4); the person prefers space that can have more than one person for socialising purposes. Another group are those who prefer a more private life after living in shared accommodations (persona 5); the person prefers a space

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that is individualistic for resting purposes. The final group are those who fall in between after living through transitional or supported housing programs (personas 1 and 6).

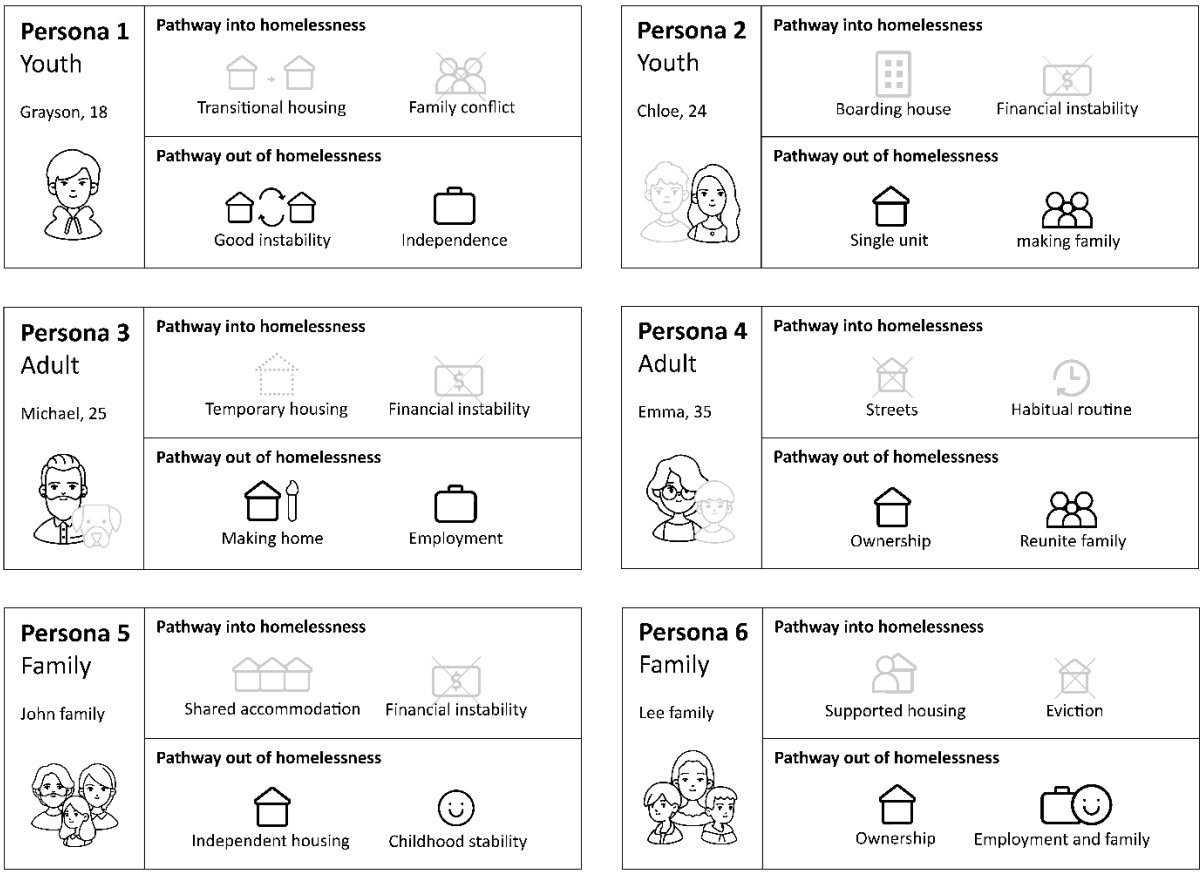

Figure 1. Engaging personas of opposite homeless experiences.

We conclude from our findings that the social complexities of homeless individuals in Melbourne, Australia are constructed of opposite housing expectations and aspirational factors based on different housing histories and causes of entry. Furthermore, the design problems that have emerged from such social complexities include 1) the tangibility of needs to be accommodated, 2) the aspirational differences to be accounted, and 3) the housing conditionalities to be addressed by future homeless housing design solutions (see Figure 2, top row).

5.2 Translation of social complexities into design complexities

Such design problems have presented a challenge for designers to better understand the testing of design extremes (i.e., the polarity of needs) in digital design processes. The acknowledgement of specific design extremes is particularly important when dealing with a module system (i.e., the framework) that is intended to offer a spectrum of housing design solutions, for a more individualised homeless housing design solution. We elaborate on such design complexities through discussions on design adaptability, design individualisation, and design mass-customisation.

Design adaptability: Designers must accommodate for all modes of communication and input of information obtained in digital design processes. Due to the very nature of dynamic homelessness and the varied timelines of housing design solutions, both tangible and intangible feedback from individuals may occur more frequently at different stages of the design process. Understanding how written, spoken, and visual forms of information are accepted by different digital design tools and technologies allow designs to progress adaptively without compromising the entire digital design process. **Design individualisation:** Designers must account for socially and personally motivated individuals. This means that digital design processes need to cater for both individual and multi-occupancy households, where both individual and collective needs must be acknowledged. For example, in a multi-occupancy household, individuals act as their own and part of a group. Understanding the relationships between

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individual and collective needs allow housing design components to be adapted as individual entities (i.e., the bedrooms) without compromising the cohesiveness of the design outcome and relationships established between individuals (i.e., the unit or house). **Design mass-customisation:** Designers must address the conditionalities of housing expectations perceived by each homeless individual. This brings about the design complexity of modular housing design solutions, where a spectrum of minimal and maximal design options for each individual program (i.e., bedrooms, kitchen, living room) are needed to allow for the varying use of private and public spaces. Understanding housing conditionalities mean that housing design solutions must acknowledge the unconventional use of spaces for greater mass-customisation. Much like the merging of office and living spaces by persona 6 to balance their work (private) and family (public) life.

We conclude from our findings that the testing of design extremes had presented a challenge for designers to address the design complexities of 1) design adaptability for written, spoken, and visual forms of information, 2) design individualisation for individual and collective needs, and 3) design mass-customisation for modular yet unconventional uses of space. All of which, aim to cater for a spectrum of designs that fall in between two opposing design extremes, for more individualised homeless housing design solutions (see Figure 2, middle row).

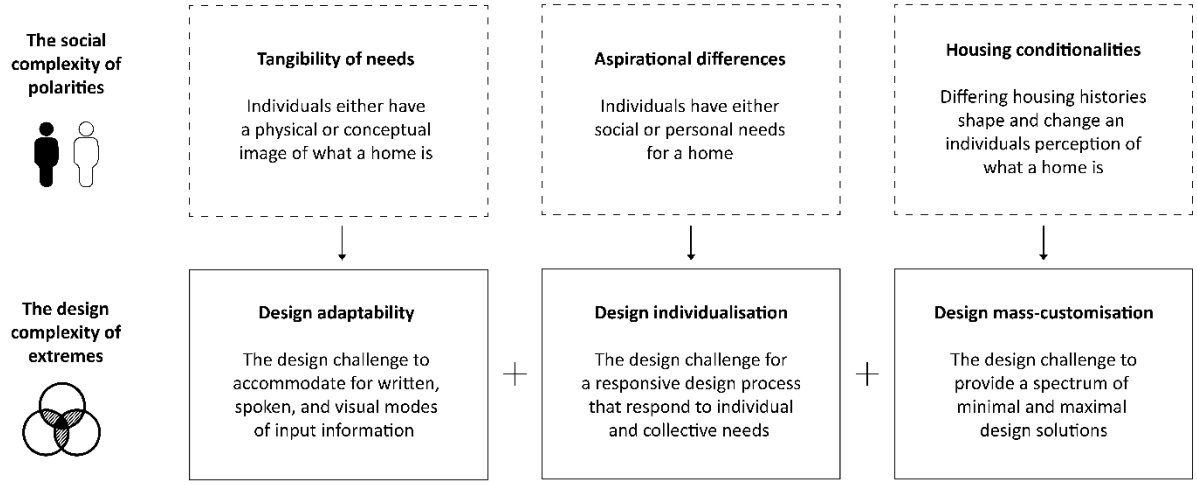

Figure 2. The social and design complexities of homeless housing design solutions.

5.3 Addressing design complexities with digital design tools and technologies

We found that such design complexities have been explored in the AEC, however, such explorations were made to address different design problems. Importantly, we found that designers had adopted digital design tools and technologies to create minimally and maximally feasible designs, to then automatically produce designs that fall in the spectrum of two design extremes. To better contextualise our findings for housing design purposes, our findings were divided into 1) site-to-design, 2) user-to-design, and 3) design-to-fabrication stages of a digital design process.

Site-to-design: To leverage digital design processes for written, spoken, and visual forms of input information, designers have previously used digital design tools to track real world information (i.e., building site information) in digital models (i.e., 3D model), so that the digital models are always reflecting live information. Specifically, we found that the disciplines of civil engineering, construction, and architecture have used Building Information Modelling (BIM) to input written building plans, material information, and construction methods to simulate and generate design solutions. Additionally, laser scanning and Augmented Reality (AR) were also used to document the formal properties of landscapes for latter digital representation and manipulation of the generated design solution. **User-to-design:** To leverage digital design processes for individual and collective needs, designers have previously automated digital models to respond instantly to changing needs. Specifically, we found that architectural practices have used parametric design tools to re-inform design solutions without the need to re-define the entire design process, such that design heuristics were able to be modified by the designer or individual user to iteratively generate design solutions based on changing needs. **Design-to-**

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fabrication: To leverage digital design processes for the varying conditionalities of housing expectations, designers have integrated digital fabrication into the design workflow to ensure the feasible production of such diverse housing design options. Specifically, we found that architects often use the combination of 3D CAD modelling software, such as Rhinoceros 3D, and additive or formative CAM technologies, such as 3D printing, to analyse, synthesise, and evaluate design solutions for low to extreme levels of design to be realized.

We conclude from our findings that existing design tools and technologies have great potential in accommodating for the design complexities surrounding design adaptability, individualisation, and mass-customisation. In our case, digital design processes are leveraged for the specific and dynamic needs of homeless individuals through the 1) synchronisation of information from the real and digital world, 2) automation of design that respond instantly to changing needs, and 3) integration of CAD and CAM for the fabrication of such diverse housing design options (refer to Figure 3).

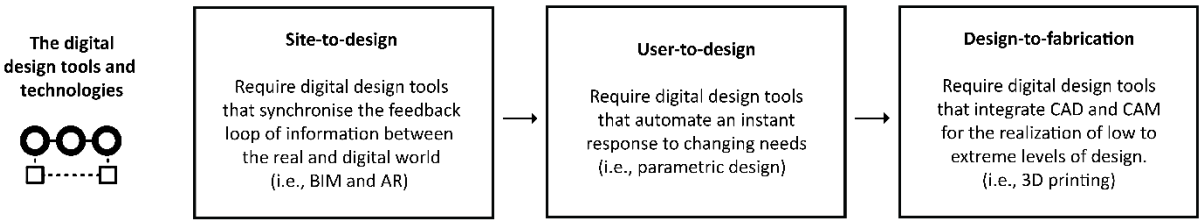

Figure 3. An adaptable, individualised, and mass-customised digital design workflow.

6 DISCUSSION

The aim of our study was to find out how digital design processes can be optimised for the specific and dynamic needs of individuals. Based on the Technological Trajectory and Lock-in theories (refer to section 3.3), it is likely that digital design processes will continue to focus only on automating and simplifying the design and fabrication workflow. The danger of such trajectories is that design outcomes become less focused on the users and more about leveraging technology. Thus, our proposed framework enables digital designers in the AEC industry to explore and digitise user needs into their existing design-to-fabrication workflows (see Figure 4):

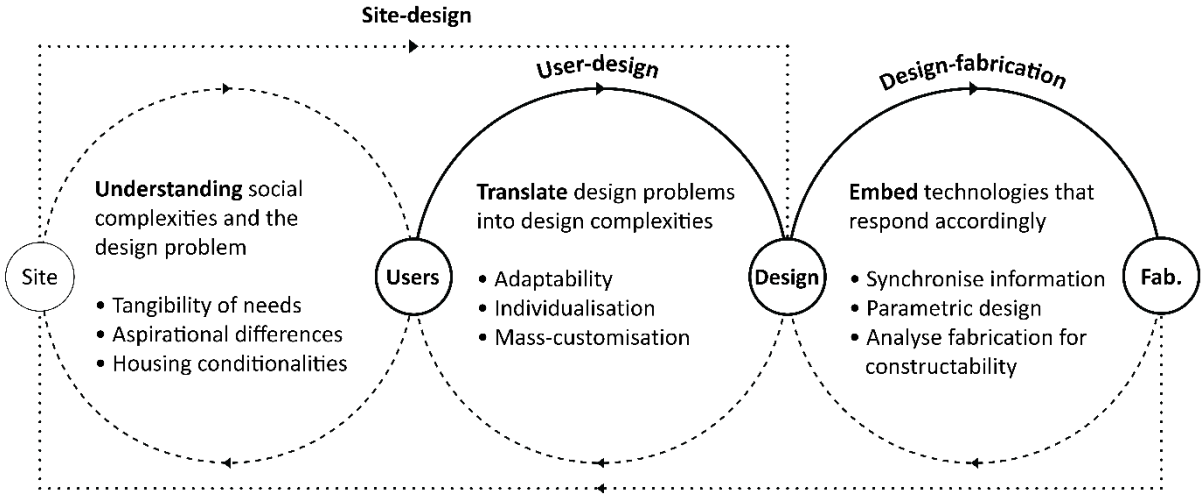

Figure 4. User-design-fabrication framework.

6.1 A User-design-fabrication framework

From our findings, the proposed user-design-fabrication framework was devised to generate more individualised homeless housing design solutions that are constructed from the specific and dynamic needs of individuals. Such a framework aims to optimise digital design processes through particular emphasis on the need to 1) understand the social complexities of a design problem, 2) translate the design problem into design complexities, to then 3) embed digital design tools and technologies that

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respond and design for the spectrum of individual needs. By encompassing the various stages of a digital user-design-fabrication process, our framework acknowledges the need for future housing design solutions to improve the level of adaptability, individualisation, and mass-customisation of its design process, to address Australia's homeless housing problem.

Despite the current discourse surrounding the popularisation of digitalisation in the AEC, our findings suggests that the focus of future research should instead examine and integrate the occupant needs as initial parts to digital design workflows in the AEC, so that the final design caters to the specific and dynamic needs of homeless individuals. Based on such findings, our research supports Li and Zhao (2016) and Wang et al.'s (2020) research on the need to forecast the impact of digital design tools and technologies in practice today. Such research has already been exemplified by Pantazis and Gerber (2019) and Freire et al. (2021), where they have shown both designers and researchers challenging the standard use of digital design tools and technologies to address other timely needs. In our case, there is now a timely need to provide more individualised homeless housing design solutions for individuals with specific and dynamic needs.

6.2 Limitations

We acknowledge one of the limitations of this paper is the lack of participants. However, this review was conducted to prevent the risks on individual wellbeing that are likely to occur when working directly with a vulnerable demographic. Additionally, the significance of this paper is the proposed framework; no such studies have attempted to uncover the hidden themes that underpin the different disciplines of homelessness, design, and fabrication. Specifically, on the merging of user-to-design and design-to-fabrication processes through a human-centric design approach. Therefore, this research responds to Petersen (2015) and Mahdi's (2021) request by investigating a novel housing design solution that purposefully explores a human-centric digital design process to assist in the design of housing for understudied populations, in our case, the homeless individuals living in Melbourne, Australia. Another limitation might be the lack of framework validation. However, testing the framework requires in-depth discussion of user customisation, digital design, and digital fabrication processes, which are outside the scope of this paper. Nonetheless, the research team has documented this work as a separate research paper (Anam and Tan, 2023).

6.3 Recommendations

Based on the above limitations, future research looking to optimise digital design processes for the specific and dynamic needs of individuals should therefore test the application of the proposed user-design-fabrication framework and adapt the complexities accordingly to their own research contexts. Such future research should also emphasise on the evaluation, synthesis, and analysis of the real-world impact of the framework applied for the purpose of achieving more human-centric design practices.

For designers attempting to address the homeless phenomena, our findings have demonstrated the new role of designers as active decision makers in understanding, translating, and embedding real-world information for digital world applications. Additionally, for designers attempting to work with homeless individuals, we emphasise on the vital first step of acknowledging such individuals as separate entities as opposed to a single demographic, where, as designers, we must continue to challenge the mainstream literature of niche populations and approach design more human-centrically.

7 CONCLUSION

The social complexities of Australia's homeless housing problem have seen a demand for more individualised housing design solutions, where heterogenous changes in societies have posed a great challenge for designers and researchers in the AEC to cater for individuals with specific and dynamic needs. For this reason, previous research have called for designers to adopt digital design tools and technologies to explore novel housing design solutions more purposefully. However, despite these recommendations, evidence to assist the design of housing for niche populations remained limited and the comparability of different disciplines of knowledge, homelessness, design, and fabrication, were understudied. To address the gap in research, we conducted a scoping review on homelessness, design, and fabrication to conceptualise a human-centric design-fabrication process. Based on our findings, we

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contribute a user-design-fabrication framework that was devised to generate more individualised homeless housing design solutions through particular emphasis on the need to understand, translate, and embed social and design complexities of a human-centric digital design process. Based on our framework, future research should 1) examine the role of designers as active decision makers in a human-centric digital design process, and 2) test the real-world application of our proposed framework in practice. Such future research will assist in the provision of more individualised homeless housing design solutions and acknowledge the increasing complexities of our current world.

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