Generative Design for the Masses:

A Toolkit for Customized Housing

DLA Doctoral Dissertation

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Abstract

The design of mass housing projects presents considerable obstacles in balancing the requirements of diverse residents with efficient and cost-effective frameworks. The emergence of generative design approaches presents a revolutionary chance to alter this industry. This study aims to overcome the constraints of standardized mass housing designs, which often lack personalization and negatively impact residents' quality of life.

This research utilizes a mixed-methods approach, which involves conducting literature reviews, case studies, and surveys of designers, developers, and residents. The objective is to assess the effectiveness of current generative design tools in the context of mass housing. The results lead to the creation of a toolkit that combines generative technologies with certain stages of the design process. This toolkit utilizes the most advantageous characteristics of novel generative design tools to optimize the process of customizing mass housing, guaranteeing both functionality and user-centered design. The primary objective of this research is to provide a meaningful contribution towards the development of housing solutions that are more sustainable, equitable, and tailored to individual needs.

Keywords: Mass housing, Customization, Generative design, Design Toolkit, Architectural design process

Declaration

The thesis is the author's own work, and it appropriately quotes texts taken word-for-word from other works and other content

The author views the thesis as his own intellectual work and only uses it for doctoral purposes in the procedure of the BME DLA

The printed and electronic copies of the thesis and the hypothesis booklet are identical in all respects.

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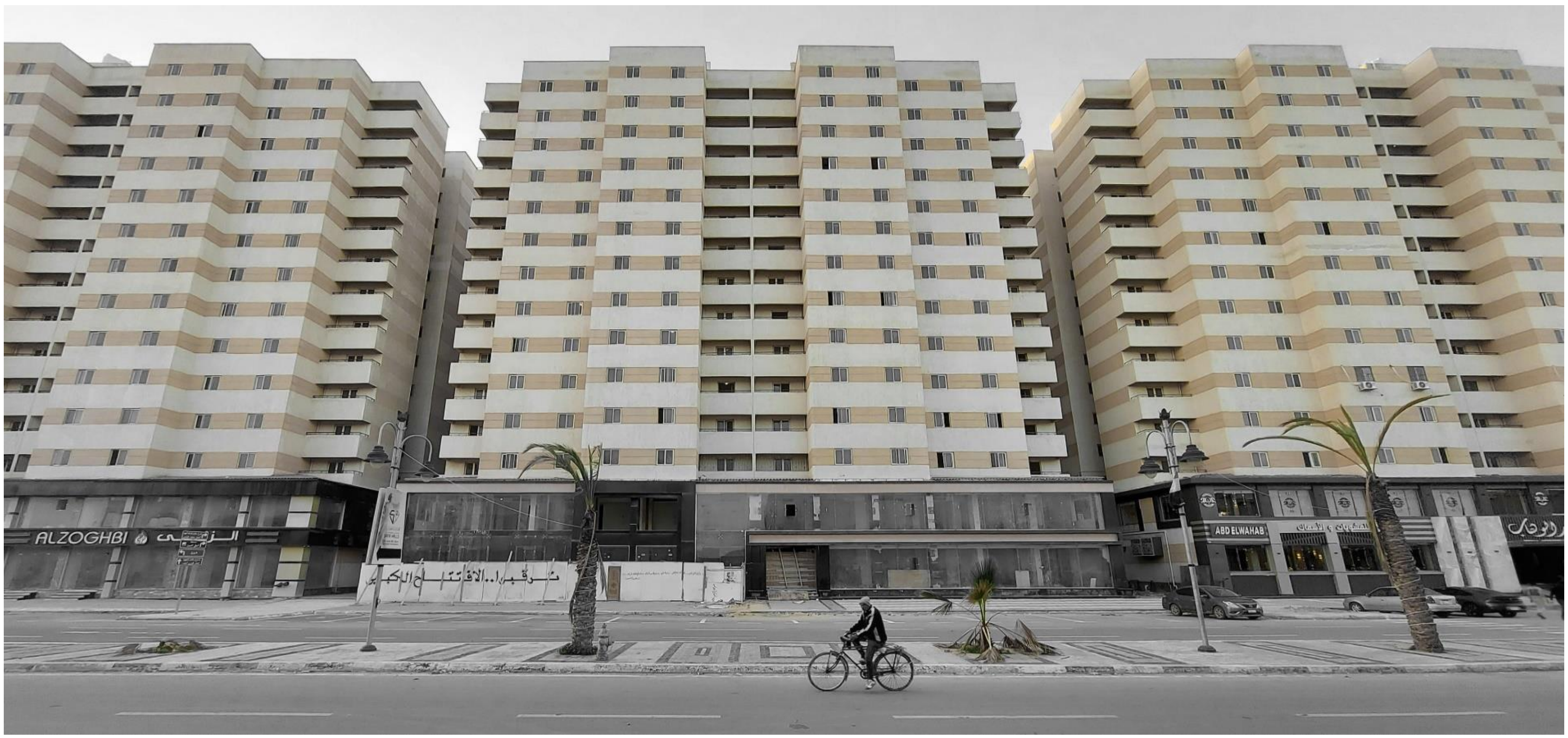

Street view of the Bashayer El-Kheir housing project in Alexandria, Egypt, displaying the imposing scale of uniform high-rise residential towers (photo taken by author)

Contents

A photo of the newly constructed mass housing project in Pardis City near Tehran, Iran (by Manuel Álvarez Diestro)

1.Introduction

1.1.Background and Context

Mass housing refers to the large-scale, construction of residential buildings, often facilitated or funded by governments or large developers, to rapidly address housing shortages, accommodate urban population growth, and achieve cost efficiency through repetitive design and industrialized building methods (Miles, 2021)

Mass housing has undergone substantial changes in order to adapt to the rapid urbanization and population expansion. The demand for effective and adaptable housing solutions has historically fueled breakthroughs in architectural design and construction (Wakely, 2014; Mumford, 1961). The main goal of mass housing is to offer cost-effective and practical residential accommodation for substantial numbers of people. Nevertheless, conventional mass housing initiatives frequently encounter criticism due to their shortcomings in personalization and inability to cater to the varied requirements of residents. Customization in mass housing has become increasingly important in recent years as a way to improve resident satisfaction and meet diverse user needs (Jensen, 2020; Larsen et al., 2019).

While this dissertation centers on customization as a key contributor to improved housing outcomes, we acknowledge that mass housing quality is shaped by multiple factors, including urban design, density, infrastructure, and social services (Shawkat, 2020; Wassenberg, 2004). Many of these aspects lie beyond this thesis's primary scope. However, prior research does suggest that the lack of customization, the inability to adapt unit layouts to diverse household needs, can intensify resident dissatisfaction and reduce overall housing quality (Larsen et al., 2019). Therefore, although we do not claim that personalization alone solves every challenge in mass housing, we conceive that insufficient customization is a significant factor limiting resident well-being and long-term adaptability in large-scale developments.

Generative design, utilizing complex algorithms and artificial intelligence (AI), offers a promising method for achieving both efficiency and customization in large-scale housing projects (Cai, 2023; Das, 2016). This methodology enables architects to examine a wide range of design options, refine solutions based on various factors, and customize designs to meet specific needs.

1.2.Problem Statement

Although generative design technologies have made significant progress, there is still a lack of their implementation in large-scale, customizable mass housing projects. Conventional design and planning approaches, which heavily depend on CAD and BIM software, face challenges in effectively addressing the needs for both scalability and personalization. This study aims to fill this gap by creating and assessing a generative design toolkit specifically designed for customizing mass housing. The goal is to connect the benefits of individual customization with the cost advantages of large-scale housing production.

1.3.Research Objectives and Questions

The primary objectives of this research are to develop a generative design toolkit and assess its impact on the customization of mass housing projects. The study aims to answer the following key research questions:

1. How can generative design tools enhance the efficiency and creativity of the mass housing design process?
2. Can a tailored generative design toolkit bridge the gap between individual housing customization and the economies of scale associated with mass housing production?
3. Does the integration of generative design in mass housing projects lead to improved sustainability and adaptability of housing solutions?
4. How does user participation in the generative design process affect satisfaction with and acceptance of mass housing projects?
5. What are the current barriers to the widespread adoption of generative design in mass housing, and how can they be mitigated through strategic toolkit development and stakeholder engagement?

6. What is the role of architects in leveraging generative design methodologies?

1.4.Scope of the Study

This study aims to assess the effectiveness of generative design methods in the specific context of mass housing projects. This thesis aims to explore the various components of generative design and their potential to revolutionize mass housing customization. By doing so, it seeks to provide a thorough understanding of how generative design can enhance the process of designing efficient, sustainable, and user-centric housing for the masses.

It is important to note that while customization is a primary research focus, we do not imply that mass housing quality depends exclusively on this factor. Broader environmental, social, and planning considerations also shape housing outcomes. We have consciously confined our investigation to the influence of generative design on the customization aspect of mass housing, acknowledging that a fully broad approach would require deeper exploration of public space design, community services, and urban-scale infrastructure

2. Methodology

Due to the nature of this research, a mixed-methods approach is considered suitable, combining both quantitative and qualitative methods. This methodology facilitates a thorough comprehension of the topic and guarantees that the results are strong and relevant to practical situations.

2.1. Literature Review

This research aims to establish a fundamental comprehension of the difficulties faced in mass housing, the principles underlying generative design, and past endeavors at their convergence. The research will be carried out using online databases such as Google Scholar, JSTOR, and library archives. The study will make use of prominent literature in the field and conduct a thematic analysis to identify recurring themes and areas that have not been adequately addressed in the existing body of work.

2.2. Qualitative Interviews

This process is being undertaken with the intention of acquiring valuable knowledge and expertise from professionals who are experts in the fields of mass housing and generative design. We did this by conducting semi-structured interviews with a select group of knowledgeable individuals. Transcription and thematic analysis will be performed on the interviews in order to identify recurrent patterns, opinions, and insights regarding the interviews.

2.3. Quantitative Surveys

Two surveys were conducted to gather empirical data from industry professionals and potential residents.

The first survey targeted housing industry professionals to understand the current use, challenges, and potential of generative design tools in architectural practice. This survey was distributed to 165 housing professionals, with 58 responses collected. The survey focused on the frequency of involvement in mass housing projects, typical design planning approaches, sustainability considerations, familiarity with generative design tools, and perceived challenges. The data collected were analyzed both quantitatively and qualitatively to identify trends and insights.

The second survey aimed to gather detailed, personalized preferences from potential residents regarding their housing needs and desires for the case study in the research. Initially, a custom NLP chatbot named "Your House - Your Choices" was tested on 10 participants to evaluate its potential. However, due to limitations in accessibility, the main data collection was conducted via an online survey advertised on social media channels. The survey focused on preferences for unit size, layout, aesthetics, sustainability features, and community amenities. The data analysis identified common themes and spatial requirements, which informed the subsequent design phases.

2.4. Toolkit Development

The evaluation criteria for generative design tools were established by drawing on insights from a thorough literature review, industry surveys, and interviews with professionals. The identification process yielded five essential design phases: functionality, usability, flexibility, integration, and scalability. The criteria were crucial in evaluating the refined selection of 40 generative design tools that are applicable to customizing mass housing. The most appropriate tools were chosen to create the generative design toolkit by assessing them based on the evaluation criteria.

2.5. Case Study: Alexandria, Egypt

The purpose of this research method is to test the toolkit in real-world scenarios and assess its viability. By identifying one mass housing projects where the generative design toolkit can be tested. The main Key Performance Indicator (KPI) employed to evaluate and contrast conventional methods and the generative design toolkit was "Time on Task." The average time required to complete the requirements of each phase was determined based on insights gathered from surveys and interviews with housing professionals. Considering that time and budget were determined to be the most prominent obstacles to mass housing customization, and recognizing that the amount of time spent creating plans directly impacts the overall cost of design services, "Time on Task" was selected as the primary key performance indicator (KPI) for comparing both traditional tools and the generative design toolkit.

A residential tower in Gheit El-Enab housing project in Alexandria, Egypt (by Author)

The multi-phased research methodology, incorporating literature review, surveys, tool evaluation, case studies, and practical evaluations, ensures a far-reaching exploration of how generative design methods can revolutionize mass housing customization. The findings aim to bridge the gap between theoretical concepts and practical applications, providing valuable insights for the architectural academia and industry.

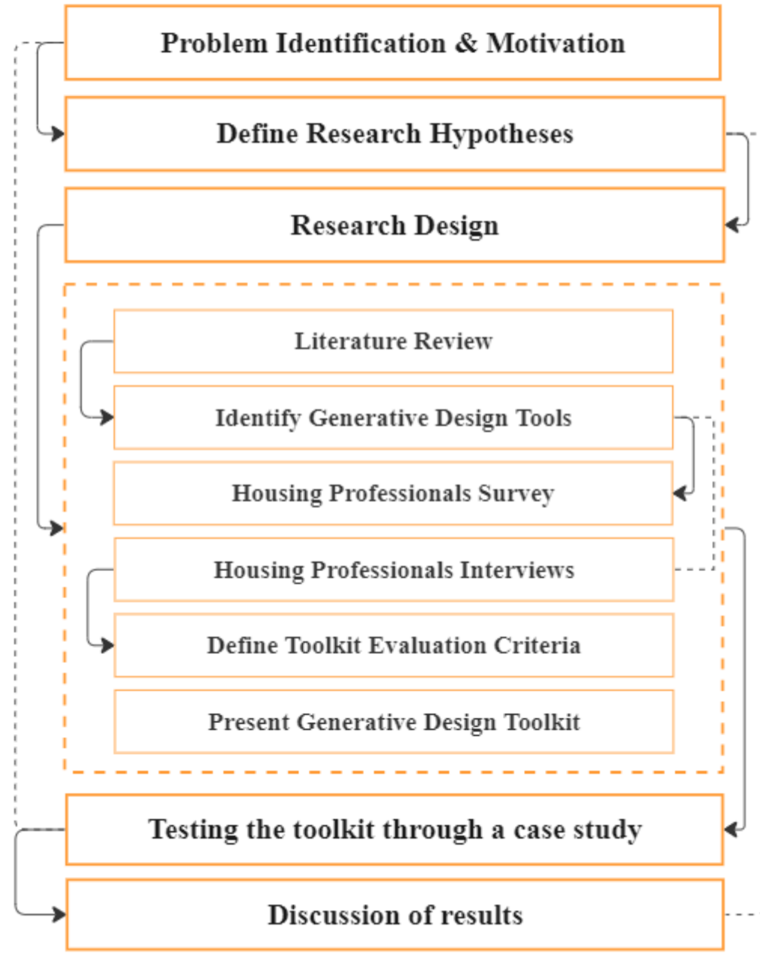

Figure 1: A diagram of the research design and the research methods utilized in this thesis.

3.Literature Review

3.1. Emergence of mass housing.

The development of mass housing has continued throughout history, driven by the pressing necessity to provide housing for expanding urban populations. Following World War II, numerous nations experienced significant housing shortages, leading governments to launch extensive housing programs (Urban, 2012). Emphasizing the need for standardized and affordable housing, efforts were made to construct high-rise apartment complexes and suburban housing projects (Miles, 2021). These initiatives were designed to rapidly offer affordable housing, often sacrificing architectural diversity and quality in the process.

The design of mass housing has been influenced by technological advancements and a better understanding of social and environmental factors in recent decades. Recent housing developments are increasingly integrating sustainable methods, designs that prioritize the needs of residents, and amenities that encourage a sense of community (Ahmed, 2021; Garip, 2021; Miles, 2021). The utilization of digital tools, such as Building Information Modeling (BIM) and computational design , has significantly improved the effectiveness, adaptability, and environmental friendliness of mass housing solutions (Adindu, 2021; Kwiecinski, 2019). This evolution signifies a transition from simply offering housing to developing habitable, resilient, and adaptable urban environments that cater to the diverse needs of modern populations.

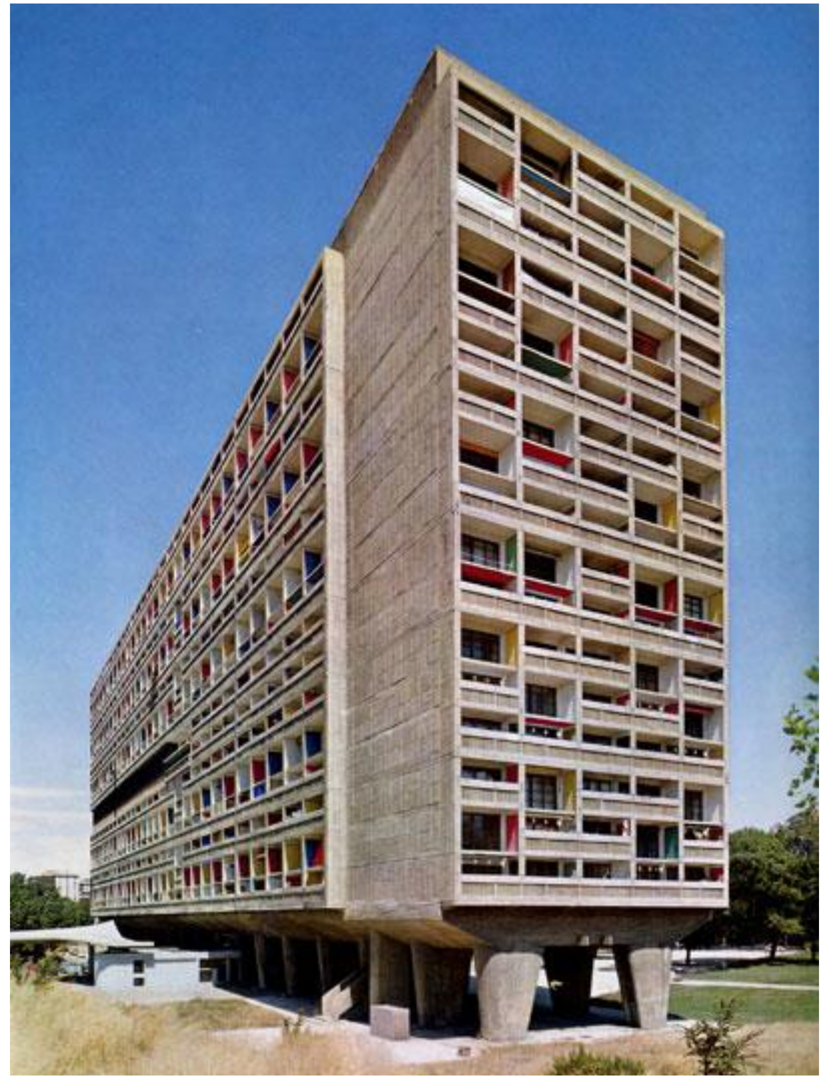

Figure 2: Unité d'Habitation, Marseille, France. (1952) Designed by Le Corbusier, this Brutalist icon redefined modern living with modular apartments and communal spaces. Photo source: iconichouses.org

Figure 3: A collection of newly developed mass housing projects from across the globe. Photos taken by Manuel Alvarez. (source: https://manuelalvarezdiestro.es/)

3.2.Mass housing Customization

Mass housing customization has become a key strategy in the housing sector, designed to achieve a balance between the demand for personalized housing solutions and the advantages of large-scale production. Mass customization is the practice of providing customers with personalized design choices at prices that are similar to those of mass production. This allows for catering to a wide range of customer preferences without sacrificing cost effectiveness. This approach is especially applicable in the housing sector, where customized living spaces have a significant influence on the quality of life.

Studies indicate that implementing mass customization in the housing industry can significantly improve customer satisfaction by offering a wide range of design options that are tailored to meet individual needs and preferences. A study conducted by Larsen et al. (2019) highlights the capacity of mass customization to decrease expenses, enhance quality, and shorten project timelines within the house building sector. The study delineates three crucial viewpoints that are indispensable for the execution of mass customization: modular and off-site construction, construction supply chains, and customer satisfaction. Although there are advantages, the study points out that there is limited research on mass customization in the house building industry, especially regarding the creation of solution space and choice navigation tools (Larsen et al., 2019).

An important obstacle in the customization of mass housing is to achieve the required adaptability to meet different customer preferences while ensuring efficient production. Khalili-Araghi and Kolarevic (2018) propose a framework that effectively combines design, customization, and manufacturing processes to tackle this challenge. Their framework prioritizes the significance of efficient collaboration among customers, designers, and manufacturers to guarantee the seamless exchange of information and the successful execution of tailored housing solutions. The study also examines the technological advancements required to facilitate such adaptability and emphasizes the challenges encountered by both companies and customers in adjusting to this approach (Khalili-Araghi & Kolarevic, 2018).

Advanced computational models and algorithms have made it easier to implement mass customization in housing. In their study, Güngör et al. (2011) devised a mass customization model that prioritizes the needs and preferences of users. They employed genetic algorithms to generate personalized housing floor plans. This model utilizes user-provided data along with optimal designs created by genetic algorithms to showcase how advanced computing can improve the customization process in housing. The study demonstrates the capacity of these models to generate extremely customized living spaces that accurately mirror the living habits and preferences of the users (Güngör et al., 2011).

Mass housing customization provides a practical solution to address the growing need for individualized living spaces while still reaping the advantages of mass production. To implement this approach, a strategy is needed that includes the use of modular construction techniques, efficient supply chain management, and refined computational models to meet the varied preferences of customers. In order to fully exploit the potential of mass customization in delivering high-quality and cost-effective housing solutions, it is imperative to conduct additional research and make technological advancements as the housing industry continues to develop.

Figure 3: Inside a unit within Harkko Housing, (2021, Helsinki - Finland) Photo: Stefan Bremer

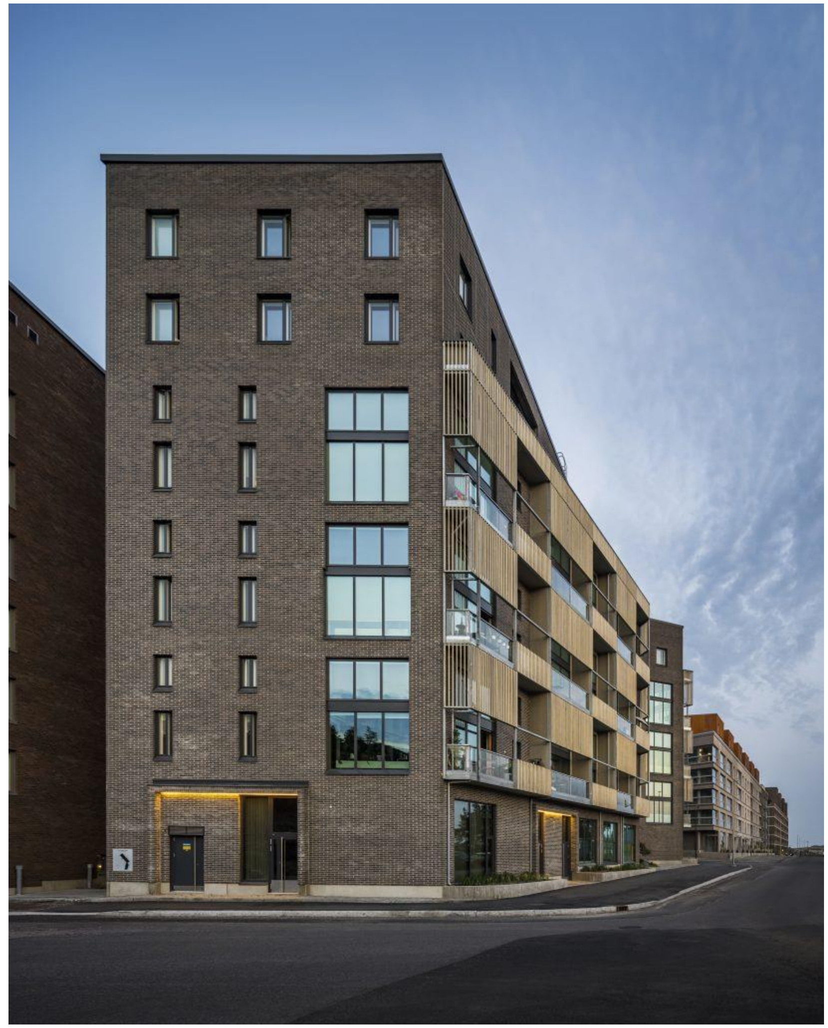

Figure 5: Harkko Housing (2021, Helsinki - Finland) offers a modular grid, enabling personalized, adaptable interior layouts. Photo: Stefan Bremer

Figure 6: Harkko Housing is a multistory residential project enabling personalized interior configurations. Photo: Stefan Bremer

3.3. Conventional or Customized Mass Housing

Mass housing customization diverges from conventional mass housing projects in various crucial aspects, prioritizing individualized housing solutions while upholding the efficiencies of large-scale manufacturing. The primary distinguishing factors between mass housing customization and conventional housing projects are as follows:

1. Personalization and Flexibility

Mass housing customization enables a substantial level of individualization. The housing units can be customized to accommodate the requirements and preferences of each individual resident, including the arrangement of rooms, finishes, and fixtures (Garip et al., 2021). The process uses versatile design frameworks that can adjust to various user specifications. The utilization of advanced computational models and modular design principles allows for the development of various configurations using standardized components (Güngör et al., 2011).

2. Advanced Technology Integration

Mass housing customization projects frequently utilize state-of-the-art digital tools, such as web-based platforms, to streamline the customization process. These tools enable customers to observe alterations in real-time and make well-informed choices regarding their designs (Bianconi et al., 2019). The incorporation of automation and prefabrication methods plays a role in achieving mass

housing customization. Prefabricated components are produced away from the construction site and then put together on-site, guaranteeing excellent quality and minimizing both construction time and expenses (Benrós & Kwiecinski, 2009).

3. Customer-Centric Approach

Mass housing customization projects differ from conventional mass housing projects in that they actively involve customers in the design process. Customers can utilize interactive tools and platforms to explicitly state their preferences and observe the impact of their choices on the ultimate design (Garip et al., 2021). Mass housing customization seeks to optimize customer satisfaction by prioritizing individual preferences and needs. Tailored solutions are more inclined to fulfill customer expectations, resulting in improved satisfaction rates in contrast to standardized housing projects (Larsen et al., 2019).

Mass housing customization sets itself apart from traditional housing projects by prioritizing individualized and adaptable designs, employing cutting-edge technology, and adopting a customer-centric approach. These factors collectively contribute to a housing solution that fulfills individual requirements while retaining the advantages of mass production, ultimately improving customer satisfaction, and decreasing construction time and costs.

Figure 7: A collection of photos showcasing Tila Housing, Helsinki Finland (2019) Source: Talli Architecture and Design Studio

3.4. Generative design in Architecture

Generative design has become a revolutionary approach in architectural practice, utilizing computational design. This exposition on generative design will examine the progression of design methodologies with the development of computers, the fundamentals of parametric design, and the vast possibilities offered by generative design.

Computers have had a growing impact on architectural design since the 1950s, particularly with the introduction of digital tools for drafting and rendering in the 1980s (Liggett, 2000). Nevertheless, these initial tools did not fundamentally change the design process but rather accelerated the production of content. The advent of parametric design software in the past decade has significantly altered the way designers interact with design processes (Jason Gerber et al., 2012). Parametric design software enables designers to define the entire design generation system, allowing them to create a variety of design variations by manipulating a set of exposed parameters. This approach not only simplifies the creation of various solutions but also enhances the flexibility of designs to accommodate future modifications.

The primary benefit of parametric design is its capacity to incorporate the limitations and goals of a design into a dynamic model, facilitating a more thorough investigation of potential design solutions (Keshavarzi, 2021; Monizza, 2018). Instead of creating just one solution, designers now have the ability to imagine a design space that has multiple

dimensions. Each dimension represents an important factor that affects the different design possibilities.

Nevertheless, the parametric design is constrained by the human designer's ability to fully explore the design space (Monizza, 2018). Generative design surpasses these limitations by allowing computers to autonomously navigate extensive design possibilities, assess alternatives, and identify promising solutions for further examination (Zhou, 2022; Zhang, 2021). This approach enables a more far-reaching investigation compared to conventional design methods by utilizing specific measurements for assessment and search algorithms to fine-tune input parameters based on feedback regarding performance.

As we continue, it is crucial to distinguish between computational, parametric, and generative design methodologies, which provide unique benefits and areas of focus. However, they frequently share the use of advanced algorithms and digital tools, resulting in some overlap. Computational design encompasses design processes that utilize computational thinking, allowing designers to utilize computation to address intricate problems that cannot be effectively tackled using traditional methods. According to Jason Gerber (2012), it offers a structure that can incorporate different specialized methods, such as parametric and generative design. Parametric design is a specific type of computational design that involves the use of parameters or variables to establish and encode connections between different design elements. This methodology enables the modification of design intentions by manipulating parameters, resulting in a high level of adaptability in design investigations (Jason Gerber, 2012).

The chosen approach in this thesis is generative design, which goes beyond parametric design. It utilizes algorithms to independently generate a diverse range of design options according to predetermined criteria and constraints. This methodology closely corresponds to the advancements in Generative AI, which encompasses artificial intelligence systems capable of producing novel content by leveraging acquired datasets and predefined rules. Generative design in architecture harnesses AI capabilities to automate the design process, optimize outcomes, and advance innovation. It enables complex problem-solving that can dynamically adapt to changing inputs and conditions (Gan, 2022). The decision to prioritize generative design in this thesis was motivated by its capacity to improve the customization and efficiency of large-scale housing projects.

3.4.1. Core Concepts

Generative design is characterized by a distinct set of core concepts that fundamentally distinguish it from traditional design methodologies. These concepts highlight the incorporation of state-of-the-art computational methods, enabling a design process that is more adaptable, responsive, and effective. By utilizing these principles, generative design not only amplifies creativity and innovation in architectural projects but also guarantees that

the designs are optimized to fulfill diverse practical and environmental standards.

Algorithmic thinking is a fundamental concept in generative design. This approach utilizes algorithms and rule-based systems to automate the design process, allowing for the examination of numerous solutions that satisfy specific criteria (Abrishami et al., 2021). Algorithmic thinking enables designers to specify parameters and constraints, which the system subsequently utilizes to produce numerous feasible design alternatives.

Parametric modeling is a fundamental principle that incorporates various parameters, including spatial needs, materials, expenses, and environmental considerations, into the design process. This integration enables the incorporation of different variations and the ability to adapt based on these defining elements, resulting in designs that are not only functional but also suitable for the specific context (Caetano et al., 2020). Parametric modeling enables designers to effortlessly modify parameters and instantly observe the impact on the design, thereby improving flexibility and efficiency.

Optimization in generative design involves using iterative procedures to search for optimal solutions within the specified parameters. This principle guarantees that the designs are not only innovative but also effective, environmentally friendly, and customized to meet user requirements (Caetano et al., 2020). Generative design achieves high-performance outcomes by continuously refining and optimizing, which traditional methods may fail to consider.

Generative design advances innovation and creativity by actively promoting exploration and diversity. This approach facilitates designers in exploring a broad spectrum of design alternatives, enabling them to discover a multitude of possibilities, resulting in more innovative and distinctive solutions (Mitchell, 2021). This principle enhances the creative capacity of designers by offering a wide range of choices to select from.

Finally, the incorporation of constraints is a methodical approach in generative design, encompassing various constraints such as regulatory, structural, and performance criteria. This guarantees that the solutions are both inventive and practical, while also adhering to the required standards (Shea et al., 2005). Generative design guarantees that the final outcomes are practical and effective by incorporating these constraints into the design process.

To summarize, the fundamental principles of generative design, including algorithmic reasoning, parametric modeling, optimization, exploration and diversity, and the incorporation of limitations, collectively establish a strong framework that improves the design process. These principles empower architects to create groundbreaking, effective, and compliant designs, representing a notable improvement over conventional methodologies.

3.4.2. Enabling Technologies

Effective implementation of generative design is contingent upon the utilization of diverse enabling technologies. These technologies offer the necessary computational power and methodologies to carry out intricate design tasks and optimize the outcomes. Architects and designers can enhance the efficiency, sustainability, and user-centeredness of their designs by utilizing these advanced systems.

Evolutionary algorithms are considered to be one of the crucial enabling technologies. These algorithms, influenced by natural selection, enable a process in which designs progress through iterations, improving solutions based on fitness criteria (Güngör et al., 2023). This approach enables the ongoing enhancement of design solutions by imitating the evolutionary process observed in nature.

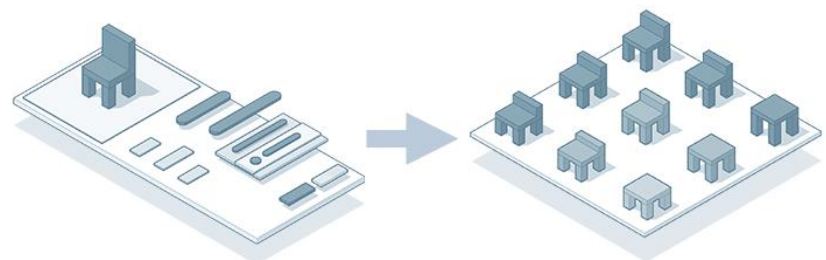

Figure 8: An illustration explaining how a set of rules, constraints and components can be utilized by generative algorithms to generate different variants. (Source:Autodesk.blogs.com)

Machine learning is a crucial technology that assists in generative design. Machine learning utilizes artificial intelligence to identify patterns, acquire knowledge from data, and improve decision-making procedures (Regenwetter et al., 2022). Generative design systems can enhance their performance by leveraging past design iterations and outcomes through learning.

Simulation and testing are essential components of generative design, encompassing thorough evaluations to assess the feasibility of design solutions based on environmental, structural, and user-centric criteria (Regenwetter et al., 2022). By utilizing simulation, designers can forecast the performance of a design under real-world circumstances, guaranteeing that the end product satisfies all essential standards and prerequisites.

Genetic algorithms, a variant of evolutionary computation, offer solutions to optimization and search problems through the utilization of techniques such as selection, crossover, and mutation (Goldberg, 1989). These algorithms are highly valuable for investigating a diverse array of design options and determining the most efficient solutions.

Agent-based modeling is a computational system that uses autonomous agents to simulate complex phenomena and generate emergent design solutions by interacting with each other and the environment (Bonabeau, 2002). This methodology enables the representation of intricate systems and behaviors, offering valuable insights into the interactions between various design components.

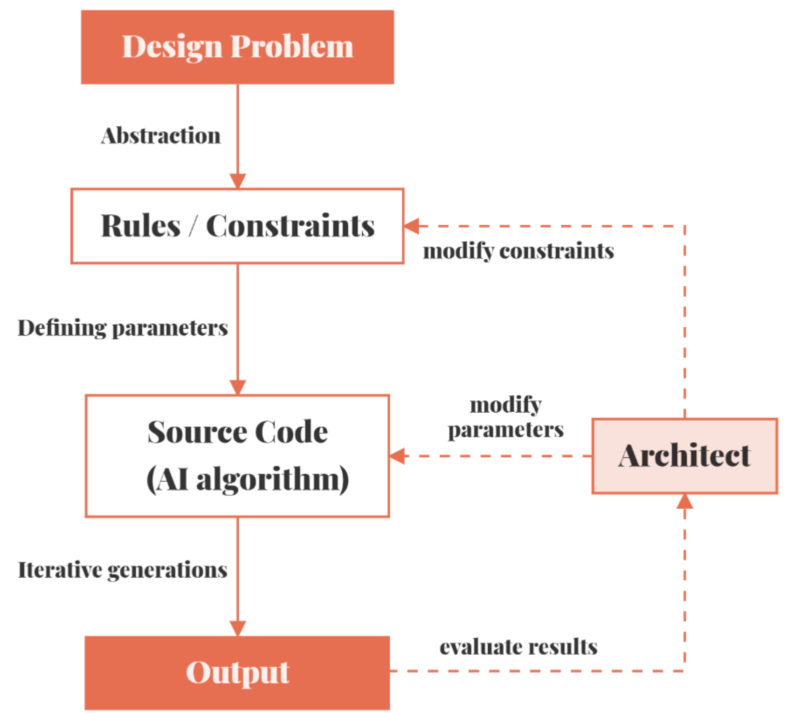

Figure 9: The diagram illustrates a process framework for solving a design problem using an AI algorithm, with an architect playing a central role. The flow starts from the design problem, abstracted into rules and constraints. These parameters define the input to the source code or AI algorithm. The AI's iterative output is then evaluated and refined by the architect, who can adjust both the constraints and parameters to influence the output until the desired results are achieved. This iterative loop between architect and AI underscores a collaborative approach to design, leveraging computational assistance for optimized results. (Source:Author)

Shape grammars are a collection of rules or algorithms that establish and produce intricate geometries and forms using predetermined parameters and patterns (Ahmed, 2021). This technology facilitates the production of complex and diverse designs by utilizing systematic algorithms to generate shapes and structures.

Topology optimization is a mathematical method that maximizes the performance of a design by optimizing the arrangement of materials within a specified space. It takes into account various loads, boundary conditions, and constraints to achieve this goal. This approach guarantees that designs are not only effective but also maximize the utilization of materials and resources.

Artificial neural networks are computational systems that are modeled after biological neural networks. They have the ability to learn from and analyze data in order to generate and improve design solutions. They excel at identifying intricate patterns and making forecasts using extensive datasets (LeCun, Bengio, & Hinton, 2015). Neural networks in architecture have the ability to analyze large quantities of design data and derive optimized solutions that fulfill specific criteria by learning from different scenarios. Neural networks are an essential technology in AI-driven architectural tools. They enable advanced generative design processes that can easily adjust to various design challenges and limitations.

The successful implementation of generative design relies on the incorporation of various advanced technologies such

as evolutionary algorithms, machine learning, simulation and testing, genetic algorithms, agent-based modeling, shape grammars, topology optimization, and artificial neural networks (Ahmed, 2021). These refined systems enable designers to develop inventive, effective, and environmentally-friendly architectural solutions that are precisely tailored to address a wide range of practical and environmental requirements.

The Role of AI in Generative Design

Artificial Intelligence (AI) has played a significant role in the rise of new generative design tools in the field of architecture. AI technologies, specifically machine learning and artificial neural networks, serve as the computational foundation for these tools. AI improves the abilities of generative design systems by examining large datasets, identifying intricate patterns, and making well-informed predictions. AI-powered tools have the ability to automate the design process, optimize solutions according to specific parameters, and adjust to changing design requirements. This leads to architectural designs that are more efficient, innovative, and focused on the needs of the user (Chaillou, 2022; Yazici, 2020). By incorporating AI into generative design, architects can expand their exploration of design possibilities, streamline decision-making, and attain greater levels of customization and performance in their projects (Millán, 2022).

Although generative design involves multiple systems and mechanisms, providing a detailed explanation of all these aspects would be lengthy and not directly pertinent to the focus of this thesis. Consequently, an examination of each mechanism is outside the limits of this discussion.

3.5. Research precedents of generative design in architecture

The incorporation of generative design in architecture has signaled a significant departure from conventional design methodologies. Generative design uses computational tools and algorithmic processes to investigate novel spatial arrangements, address site-specific obstacles, and enhance sustainability and user experience. This approach has been increasingly utilized to meet the intricate requirements of architectural and urban planning projects.

An exemplary instance is the investigation conducted by Nardelli (2023), which delves into the utilization of generative design to augment the Brazilian social housing initiative "My Home My Life." This study examines the excessive expenses associated with urban land and the distinctive features of different areas, showcasing how generative design can effectively adjust to a wide range of complex environments. In a comparable manner, Cai et al. (2023) developed DesignAID, a generative artificial intelligence tool that assists in the initial stages of creative design by producing a wide range of visual images based on verbal descriptions. This tool helps designers overcome fixation and enables them to explore a wider array of possibilities.

Ji et al. (2023) examine the combination of generative design and performance-based methods to enhance environmental factors like thermal comfort, daylighting, and solar radiation performance. They emphasize the contribution of generative design in advancing sustainability. Wei et al. (2022) investigate the capabilities of generative design in modular construction and illustrate its efficacy in automating and improving residential building designs.

Chillou (2019) presents ArchiGAN, which is a framework that uses Generative Adversarial Networks (GANs) to aid in the design of apartment buildings, specifically through a three-step process: building footprint massing, program repartition, and furniture layout. By nesting GAN models for each of these steps, the system generates entire building designs, allowing architects to adjust the results iteratively. The framework is designed to support multi-apartment buildings and includes user inputs for refinement, demonstrating a shift from traditional deterministic design processes to more holistic, data-driven approaches (Figure 10 &11).

Further research highlights the flexibility and influence of generative design in the field of architecture. AlOmani and El-Rayes (2020) use image processing to produce optimal thematic architectural layouts, demonstrating the effectiveness of automation in generating diverse configurations. Das et al. (2016) present the Space Plan Generator, a tool that utilizes generative algorithms to efficiently explore multiple spatial arrangements. Zhang, Liu, and Wang (2021) highlight the importance of enhancing the efficiency of residential buildings by utilizing parametric algorithms. In contrast, Di et al. (2020) propose a method that generates intricate and logically connected building layouts by incorporating attributes and relation graphs.

Additional notable contributions consist of the development of GoDesign by Azadi and Nourian (2021), which is a modular framework for achieving mass customization in architectural design. Furthermore, Mukkavaara and Sandberg (2020) demonstrated the application of generative design in a case study involving the exploration of architectural design in a residential block. Bianconi, Filippucci, and Buffi (2019) investigate the utilization of a web-based catalog for automated design and modeling of mass-customized housing. Meanwhile, Li and Lachmayer (2019) emphasize the significance of employing generative approaches to explore design solution spaces. Weber, Mueller, and Reinhart (2022) critically examine the techniques used for automated floorplan generation, focusing on advancements and difficulties. In contrast, Upasani, Shekhawat, and Sachdeva (2020) specifically explore the automated creation of dimensioned rectangular floorplans. In their 2017 paper, Nagy, Villaggi, and Zhao introduce an innovative framework for generative space planning that goes beyond conventional heuristics.

These studies demonstrate the wide-ranging usefulness and revolutionary possibilities of generative design in

architecture. Generative design utilizes sophisticated computational techniques to improve creativity, efficiency, and sustainability in architectural practices, leading to the development of more adaptable and inventive built environments.

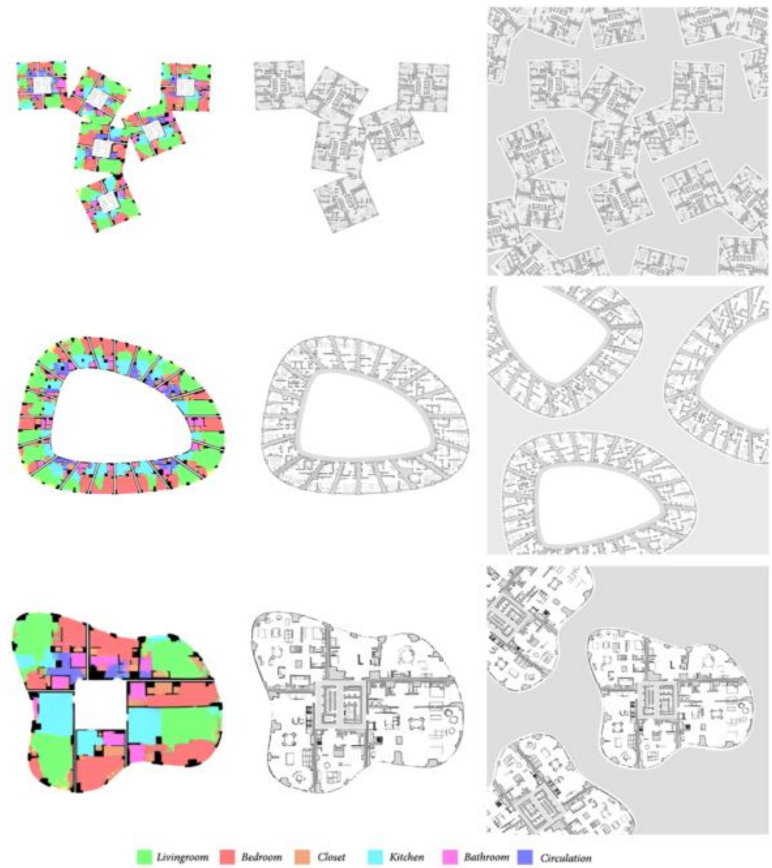

*Figure 10: **Building layouts by** ArchiGAN: a Generative Stack for Apartment Building Design (Source: Chaillou, 2019)*

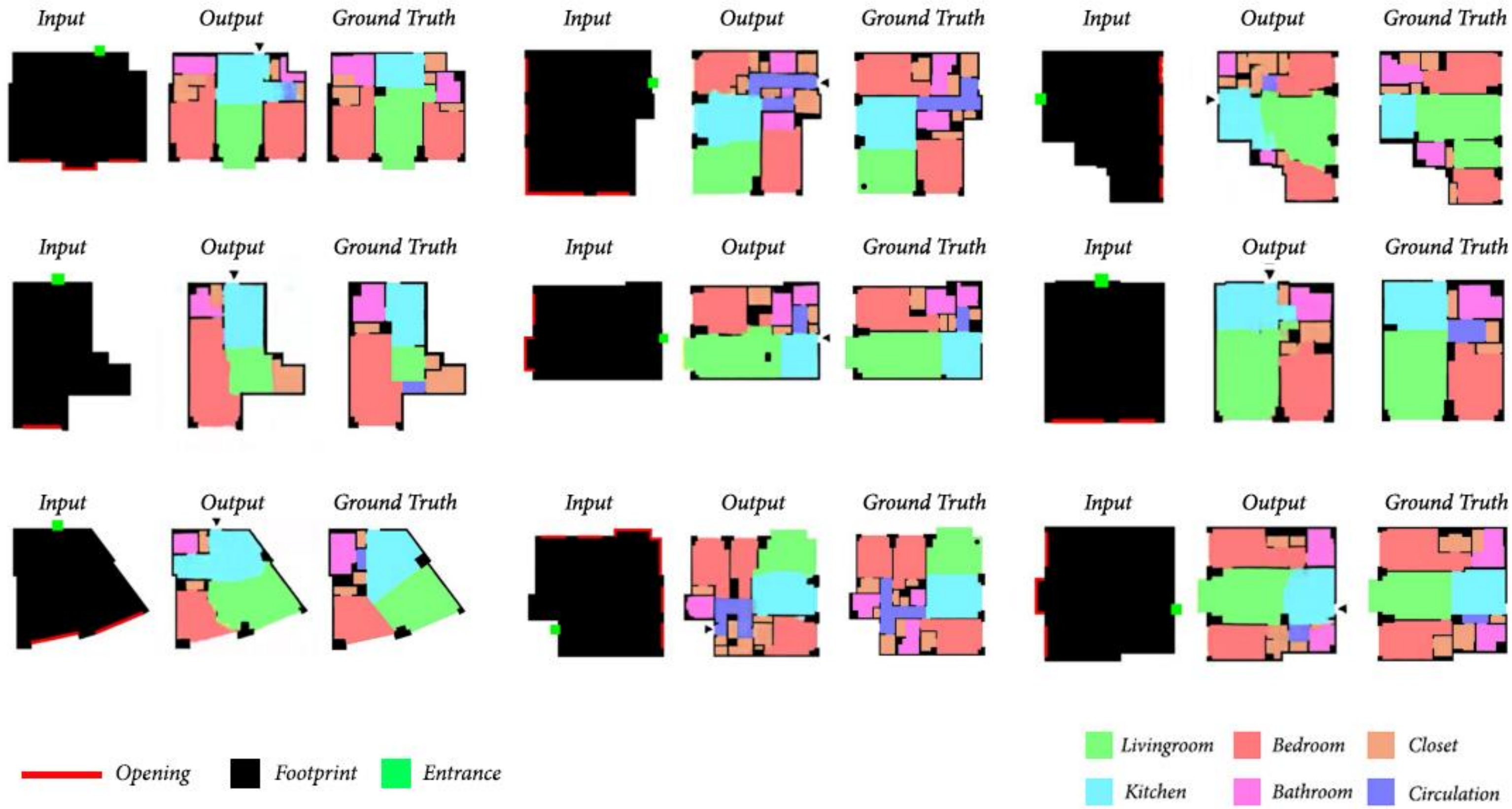

Figure 4: A diagram showing the different of the ArchiGAN framework. Source: (Chillou, 2019)

3.6. Status of generative AI tools for architects

3.6.1. The emergence of AI Generative Design tools

Starting from 2022, there has been a significant increase in both the variety and capabilities of generative design tools supported by artificial intelligence (AI) (Cai et al., 2023; Ko et al., 2023; Yuhi Maeda & Keita Kado, 2023). The progress in machine learning, neural networks, and deep learning has significantly enhanced the capabilities of generative design, allowing for more flexible and reactive design procedures. However, there is a lack of literature that analyzes these new tools, their applications, comparative efficiencies, and potential impact on the architectural world.

3.6.2. State of AI in architecture survey

Architizer and Chaos conducted a large-scale survey to understand the current and future effects of Artificial Intelligence (AI) on architecture. The survey collected feedback from a diverse international audience of architects and design professionals. This report, with over 1,200 professionals from 118 countries, shows how AI technologies are being integrated into architectural workflows, the challenges professionals face, and the expectations for AI's role in architectural design (Architizer, 2024).

AI integration is a major trend in architecture, according to the survey. With 46% of respondents using AI tools in their projects and 23% planning to do so soon, AI is changing architectural practices. The widespread adoption of technologically driven design processes is thought to improve efficiency, creativity, and the ability to solve complex design problems.

Figure 5: A screenshot from the survey, highlighting the perceived potential of AI for architects surved. (Source: Architizer, 2024)

Even though professionals love AI tools, 60% of respondents lack formal training in using AI for architectural design. This gap highlights a critical area for educational institutions and industry leaders: developing training programs to equip architects with AI skills. Professionals' self-learning and experimentation suggest a proactive community approach but also highlight the need for structured educational frameworks.

In addition, the survey reveals AI's most useful applications. Respondents were satisfied with AI's performance during early design, when AI tools can be fully utilized for flexibility and rapid iteration. As projects enter more detailed and regulated stages like design development and beyond, satisfaction levels drop. This shows that AI tools cannot handle the fine details and precision needed in later architectural projects.

The steep learning curve of new technologies, integration issues with existing software, and lack of suitable training resources are major challenges. These obstacles hinder the seamless adoption of AI in everyday architectural tasks and reflect the industry's early AI integration. Better software compatibility, user-friendly interfaces, and support materials could improve AI's utility and acceptance.

AI technologies have transformed architectural practice, according to this survey. Early adoption and the potential for AI to revolutionize the field are evident, but training, integration, and scaling AI applications to meet all architectural needs are still needed. AI in architecture will be

guided by user insights as the industry navigates these challenges, ensuring that it enhances design creativity and complements technical rigor in later project stages.

3.7.Gaps in the literature and justification for research.

The literature on generative design in architecture and housing has been prolific, with considerable exploration into its foundational principles, methodologies, and specific applications. As with all rapidly evolving fields, gaps emerge, prompting the necessity for further research and inquiry. Particularly with the rise of AI-supported generative design tools during 2022, the landscape has undergone major shifts, leading to both exciting possibilities and areas yet to be explored in depth.

3.7.1.Gaps in the Literature

Reviewing literature on generative design in architecture and urban planning reveals a notable gap in applying this technology to mass housing customization. The potential for tailoring mass housing to individual preferences and local contexts remains insufficiently explored. However, the following gaps can be observed:

1. There is a lack of detailed exploration into how generative design can bridge the gap between the standardization inherent in mass housing and the personalization required to meet diverse end-user needs.

2. There is a gap in understanding the extent to which generative design can facilitate user participation in the design process, allowing future residents to customize their living spaces within the constraints of mass housing.
3. While there have been mentions and case studies of specific AI-powered generative design tools, there lacks a holistic overview. A systematic review mapping the landscape of such tools, their strengths, limitations, and areas of application, is noticeably absent.
4. With AI bringing in more automation, the user's role in the design process might see shifts. Research addressing the changing dynamics of user-designer interactions, user experience, and feedback mechanisms in AI-powered generative designs is yet to gain momentum.

3.7.2.Justification for Research

These gaps suggest a need for more thorough research on how generative design can be effectively and economically applied to the mass housing sector, with a focus on customization, cost-effectiveness, user engagement, compliance with regulations, and technological accessibility. The case study presented addresses the identified gap in the literature by demonstrating how generative design tools can effectively bridge the gap between standardization and personalization. This practical application provides a concrete example of how theoretical insights can be translated into actionable design strategies.

Addressing these gaps could lead to a more sophisticated understanding of the role of generative design in mass housing and its potential to contribute to more personalized, culturally relevant, and sustainable living environments.

Given the aforementioned gaps, the present research is timely and essential. It aims to provide:

- An ample overview of the AI-supported generative design tools emerging post-2022, filling a critical void in current literature.
- Analytical insights into the practical applications, challenges, and outcomes of these tools, offering practitioners valuable guidance.
- A discourse on the evolving dynamics between users, designers, and AI algorithms, emphasizing user experience and feedback loops.

4. Toolkit Development

Generative design utilizes artificial intelligence systems to produce diverse forms of content, such as text, images, 3D models, and audio. It particularly emphasizes the use of extensive language models and text-to-image models. This is especially pertinent in the context of creative thinking and the stages of generating ideas in design, where the process is marked by a constant transition between modes of thinking that explore different possibilities and modes of thinking that narrow down options (Yuhi Maeda & Keita Kado, 2023).

We will compile an inclusive list of generative design tools that are appropriate for each stage of the mass housing design process. Additionally, we will conduct a thorough evaluation of these tools to determine their potential for optimizing customization. This dual approach guarantees that the tools identified are not only effective but also capable of being adjusted to meet the various requirements of mass housing customization.

4.1.Generative design tools potential survey

A survey was conducted among housing professionals to gather empirical data on the use, challenges, and potential of generative design in mass housing projects.

4.1.1.Survey process

The survey was organized into six primary sections, each specifically aimed at capturing a unique aspect of housing design and perception concerning generative design. The survey participants consisted of professionals from different firms, positions, and years of experience, ensuring a diverse range of perspectives. The main areas of investigation encompassed the frequency of participation in mass housing projects, conventional design planning methods, sustainability factors, familiarity and utilization of generative design tools, and perceived obstacles in implementing such technologies.

4.1.2.Survey Planning and Execution

The survey was designed to collect both quantitative and qualitative feedback, thereby providing a broad understanding of current practices and perceptions in mass housing design. A total of 165 architecture professionals were invited to participate under a non-disclosure agreement that facilitated direct communication and ensured data confidentiality. Of these, 58 completed the survey. In terms of geographic distribution, approximately 30% were based in Europe, 30% in Asia (including Japan and Singapore), 20% in the United States, 10% in South America, and the remaining 10% in Egypt. This global scope yielded valuable insights into how considerations such as budget constraints, sustainability priorities, and iterative design processes are approached in a variety of cultural and professional contexts.

4.1.3.Survey insights

The respondents possess a diverse spectrum of expertise in the subject of architecture, spanning from 1 to 33 years, with an average of 15.5 years. This varied experience offers a complete outlook on large-scale housing initiatives.

The respondents participate in mass housing projects at different intervals, with "Occasionally" being the most prevalent response (29.31%), followed by "Always" and "Rarely" (both 25.86%).

The findings about the difficulties of house customization reveal that the main issues for respondents are time and budget constraints, accounting for approximately 31% and 28% of the responses, respectively. Building codes and regulations pose significant issues, constituting approximately 16% of the criticism. Seventeen percent of participants have emphasized the significance of site context considerations, indicating the importance of location-specific elements in housing projects. While less commonly mentioned at around 9%, catering to the varying demands of inhabitants demonstrates an understanding of the need of accommodating different preferences and requirements in home designs.

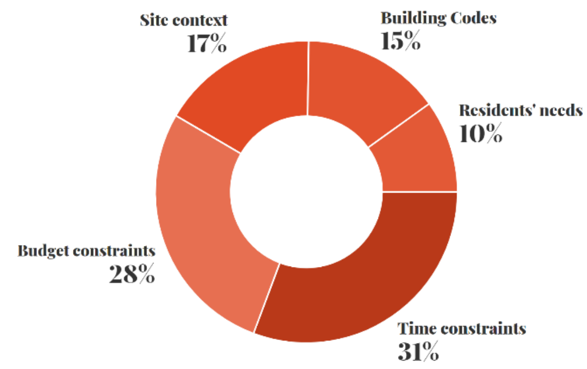

Figure 6: This chart presents the distribution of various challenges in housing customization (based on survey results)

- The majority of respondents surveyed lean towards efficiency in their design process for mass housing projects, with 56% completing fewer than 3 iterations. A substantial 30% engage in a moderate amount of design refinement, executing 3-5 iterations. A smaller segment, 8%, undertake a more extensive design process with 6-10 iterations, and a minimal 6% exceed 10 iterations, indicating a highly customized approach. This data reflects the varying strategies firms use to balance the demands of efficiency, customization, and project complexity.
- Familiarity with generative design tools is mixed, with a higher percentage of respondents being "Not familiar" (44.83%) or "Somewhat familiar" (36.21%). Among those who have used generative design tools,

there is an even split between those who have and those who find the concept not applicable to their practice (both 36.21%).

- The biggest challenge foreseen in adopting a generative design toolkit for mass housing projects is "Technical Complexity" (39.31%). In the context of this survey, technical complexity encompassed several factors, including the steep learning curve for advanced parametric or AI-driven tools, the combination of multiple software platforms within a single workflow, and the difficulty of bridging design data across various project phases. This finding emphasizes the need for user-friendly and well-documented solutions that can be easily integrated into architectural practices. Other notable challenges include the need for “Training” (20.69%) and “Integration with existing workflows” (18.97%). Other notable challenges include the need for "Training" (20.69%) and "Integration with existing workflows" (18.97%).

Conclusion

The survey results indicate a noteworthy interest in and potential for generative design tools in mass housing projects, particularly regarding budget considerations, sustainability, and the iterative nature of the design process. However, challenges such as technical complexity, the need for training, and integration with current workflows must be addressed. These insights can guide the development of

your generative design toolkit, ensuring it meets the needs and overcomes the barriers identified by professionals in the field.

4.2.Mass Housing Customization Design Process

The design and development of mass housing projects can be broadly divided into several main phases. Each phase is integral to understanding the process of creating mass housing that meets both economic goals and the individual needs of residents. The phases are:

4.2.1.Conceptualization and Planning

The conceptualization and planning phase serves as the fundamental basis for any mass housing project. It entails establishing project objectives, determining the intended audience, and formulating preliminary design concepts. This stage is crucial for comprehending the market demand, housing requirements, and preferences of prospective residents (Garip, 2021). Market research and demographic studies are essential in this phase as they assist in determining the specific sorts of housing units needed and the characteristics that will attract different sectors of the population (Larsen, 2019). Furthermore, this stage encompasses the process of choosing a location, taking into account aspects such as the accessibility to facilities, transportation connections, and environmental circumstances. Regulatory requirements, such as zoning regulations and construction codes are identified to guarantee compliance and streamline project implementation.

4.2.2. Feasibility Studies

Feasibility studies are crucial for evaluating the practicability and financial feasibility of the proposed housing project. This stage entails an examination of multiple aspects, such as land utilization, environmental consequences, economic viability, and adherence to regulations. Land use analysis assesses the most efficient use of a location, taking into account zoning regulations and urban planning principles (Havard, 2013). Economic feasibility evaluates the project's financial sustainability by analyzing precise cost predictions, which encompass construction costs, material expenses, labor, and long-term maintenance (Havard, 2013). This phase also guarantees that the project plans comply with local building rules and environmental regulations, which may include several revisions and meetings with regulatory authorities.

4.2.3. Design Development

The design development process converts preliminary concepts into more developed and detailed architectural plans. Architects enhance floor designs, create intricate layouts, and choose the materials, structural components, and mechanical, electrical, and plumbing (MEP) systems. This stage entails the development of detailed drawings and specifications that will serve as a blueprint for the construction process (Garip, 2021). At this stage, customization focuses on meeting the particular

requirements and preferences of future occupants. This ensures that the design of the space is able to accommodate varying family sizes, lifestyles, and future changes by being flexible and adaptable (da Rocha, 2016). The process of detailed design development also requires close cooperation with other stakeholders, such as engineers and contractors, to guarantee the smooth integration of all technical elements into the overall design.

4.2.4. Environmental and Sustainability Analysis

Modern mass housing projects must prioritize sustainability as a fundamental aspect. The phase of environmental and sustainability analysis evaluates the project's influence on the environment and discovers possibilities for integrating sustainable design concepts. This encompasses the assessment of energy efficiency, water preservation, waste handling, and the utilization of sustainable materials (Dalla, 2021). One may pursue green building certifications, such as LEED or BREEAM, to guarantee that the project adheres to rigorous environmental performance criteria. This phase also encompasses the evaluation of the housing development's long-term viability, which includes assessing the feasibility of incorporating renewable energy sources, implementing sustainable landscaping practices, and encouraging people to adopt sustainable living habits (Dalla, 2021).

4.2.5. Visualization and Inspiration

The visualization and inspiration phase include generating visual depictions of the proposed ideas to enhance stakeholder participation and decision-making. This stage uses refined visualization methods, such as 3D modeling, virtual reality, and augmented reality, to offer a lifelike representation of the housing project (Eloy, 2021). Visualizations facilitate the transmission of design concepts to stakeholders, such as potential residents, investors, and regulatory authorities, allowing them to offer comments and make well-informed decisions (Eid, 2017; Chaszar, 2016). This phase also includes the creation of compelling visual narratives that showcase the distinctive characteristics, design aesthetics, and possible advantages of the project.

4.2.6.Stakeholders Involvement and Customization

It is essential to involve potential inhabitants in the design phase to ensure that the housing created aligns with their specific requirements and preferences. During the customer involvement and customization phase, residents are provided with configurators or design tools to choose finishes, layouts, and additional features for their units (Leckner et al., 2003). By using a participatory approach, the final design is able to include the varied preferences of future residents, so increasing their sense of ownership and happiness. Architects can make data-driven decisions and develop designs by gathering feedback through surveys, workshops, and focus groups (Adindu, 2021). This stage also facilitates the identification of any particular requirements or limitations that must be taken into account in the ultimate design.

By adhering to these stages, developers and designers can attain a harmonious equilibrium between the financial benefits of large-scale production and the customization sought by residents, resulting in more gratifying and enduring housing solutions (dos Santos, 2020). An integrated approach to mass housing customization is achieved by an emphasis on conceptualization, feasibility, precise design, sustainability, visualization, and customer interaction.

Conclusion

These phases represent a framework for the design and development of mass housing projects, incorporating mass customization principles. By following these phases, developers and designers can achieve a balance between the economic advantages of mass production and the personalization desired by residents, leading to more satisfactory and sustainable housing solutions. The scope of this research is about the design phases, so the construction and post-occupancy evaluation will not be investigated in this thesis.

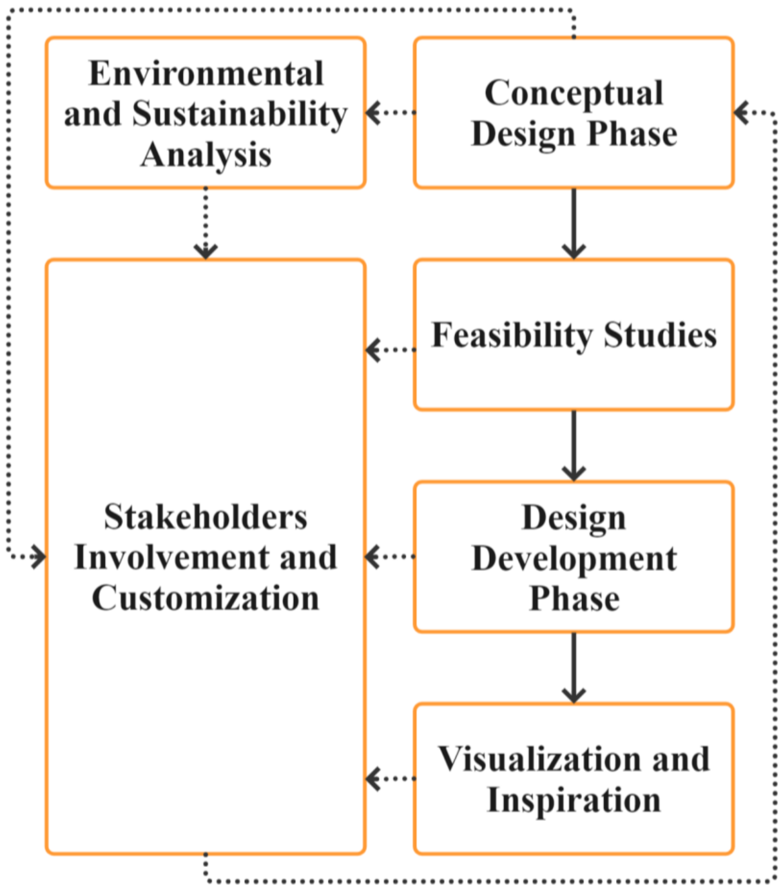

Figure 74: The diagram outlines a design process for mass housing customization based on the insights from the literature, featuring interconnected phases. It begins with the Conceptual Design Phase, which feeds into Feasibility Studies and progresses to the Design Development Phase. Integral to this process is the Stakeholders involvement and customization, influencing and being influenced by all stages. The process is iterative, with feedback loops allowing for adjustments and refinements across all phases to ensure alignment with project requirements and stakeholder needs. (Source: Author)

4.3.Overview of the generative design tools

A wide-ranging selection procedure was conducted to identify all relevant generative design technologies for mass house customization accessible in the market until February 2024, with the aim of creating an efficient toolkit. The selection process was crucial in ensuring that the toolkit would include the most state-of-the-art and effective solutions to tackle the specific difficulties of mass housing projects.

The first phase entailed doing a thorough market survey to get a compilation of generative design tools. Subsequently, these technologies underwent a thorough assessment using a predetermined set of criteria specifically formulated to gauge their usefulness, usability, flexibility, integration possibilities, and scalability. The evaluation criteria, which will be outlined in the next section, were designed to guarantee that the chosen tools would satisfy the rigorous standards necessary for effective, sustainable, and user-focused mass housing design.

By specifically considering tools that utilize generative design technologies, the review process assured that the final toolkit would not only automate design processes but also offer creative solutions powered by artificial intelligence. This method ensures that the toolkit is fully prepared to address the intricacies of customizing mass housing, resulting in designs that are both efficient and capable of adapting to a wide range of resident needs.

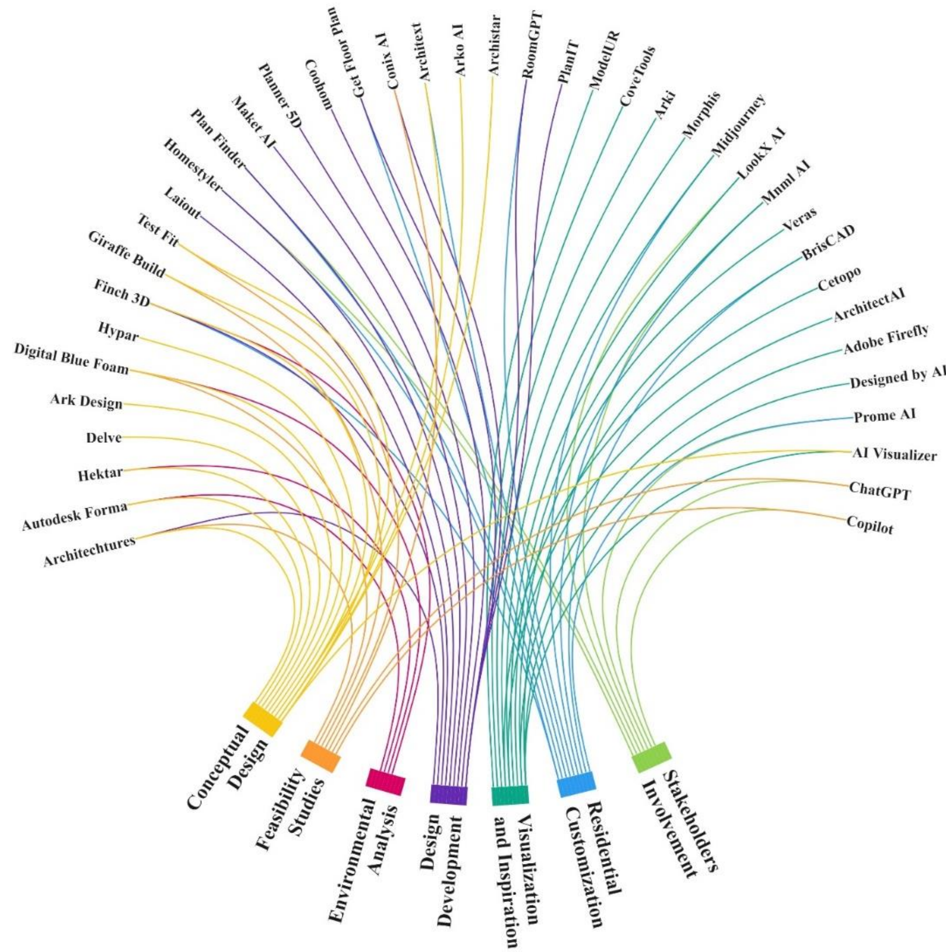

Figure 15: The diagram on the right, showcases relevant generative design tools for mass housing customization, mapping them to the specific phases of the customization process they best support. Each of the 40 tools, is linked to one or more phases, illustrating their optimal application in aiding and streamlining the respective stages of the housing customization workflow. (Source: author)

The tools that were chosen, based on our evaluation criteria and achieved the best scores, make up the essential components of the generative design toolkit. These tools have the potential to completely transform the architectural design process, allowing architects and planners to quickly create, assess, and improve design choices in ways that were previously inconceivable.

4.4. Evaluation Criteria

To choose the most efficient AI generative design tools for customizing mass housing, it is necessary to have a strong evaluation criteria (Zhao, 2018). By conducting a thorough examination of existing literature, consulting with experts, and analyzing current practices in the business, we have determined five crucial criteria that are necessary for evaluating these tools: functionality, usability, flexibility, integration, and scalability.

4.4.1. Functionality

Functionality refers to the variety of activities and tasks that a software product can accomplish. For mass home customization, the tool should be able to accurately generate different design variants, consider local construction codes, and give solutions that cater to varied user preferences (Weber et al., 2022; Azadi, 2021; Di et al., 2020). The capacity to automatically produce many design iterations based on established limitations and parameters is vital for customization (Kjelddnielsenn et al., 2017).

4.4.2. Usability

Usability refers to the degree of user-friendliness and intuitiveness of a software application, guaranteeing that users can accomplish their goals efficiently, effectively, and with satisfaction (Abrishami et al., 2021; Albers, 2011). Architects and designers desire a tool that simplifies the learning process and enables a smooth design process due to the intricate nature of housing customization. An interface that is easy to use, provides clear visual information, and offers user advice can simplify the customization process, enabling quick iteration and improvement (Zhao, 2018).

4.4.3. Flexibility

Flexibility refers to the tool's capacity to adapt to different project environments, construction codes, and specific project constraints. Mass housing projects frequently encompass a wide range of environments, including both urban and suburban areas, each with its own distinct obstacles. A versatile tool may adjust to different circumstances, guaranteeing that the customization is relevant to the specific context, visually appealing, and operationally effective. The ability to adapt is crucial when dealing with distinctive client demands or obstacles peculiar to a particular site (Azhar et al., 2009; Zhao, 2018).

4.4.4. Integration

Integration evaluates the tool's ability to effectively operate alongside other software platforms and systems, guaranteeing seamless data interchange and collaborative work. Architectural design, particularly in the field of mass housing, frequently necessitates the utilization of several software solutions, ranging from CAD platforms to energy analysis tools. Seamless integration guarantees that tailored designs may effortlessly be transmitted, examined, and improved across platforms without any loss or distortion of data. This feature is essential for multidisciplinary collaboration and design review (Azhar et al., 2009).

4.4.5. Scalability

Scalability pertains to the tool's ability to manage an increase in project scale or complexity without experiencing a decline in performance. Mass housing projects can vary in size, ranging from block scaled complexes to neighborhood-scale residential constructions (Urban, 2012). A scalable tool guarantees that if the project expands in intricacy or magnitude, the customization procedure stays efficient (Upasani et al., 2020). This is especially relevant when creating several design alternatives for larger projects, guaranteeing prompt delivery and optimal performance (Uzunoğlu & Özer, 2014).

This criteria were selected to ensure that the tools chosen for the toolkit not only fulfill the technical and operational requirements of mass housing projects but also improve the

complete design process, from the initial idea to the final execution.

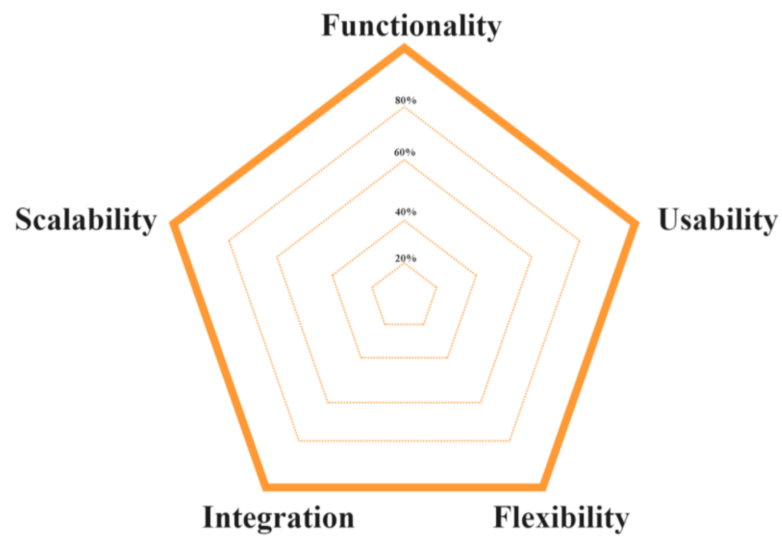

Figure 16: The pentagon chart displays the five criteria proposed to evaluate the selected generative design tools: Functionality, Usability, Flexibility, Integration, and Scalability. Each axis represents one criterion, and the extent to which a tool meets each criteerion can be plotted within this framework to visually assess and compare the overall performance and suitability of different tools in supporting mass housing customization. (Source:author)

4.5.Insights from Professional Interviews on Mass Housing Customization

This part presents a compilation of the knowledge acquired from a series of interviews with seven experts in the field of mass housing. These interviews were crucial in comprehending the varied viewpoints and difficulties encountered in the area. The findings have been essential in determining the evaluation criteria listed in the previous section for the proposed generative design toolkit, specifically customizing it to meet the requirements of mass home customization.

4.5.1.Interview Process and Participant Backgrounds

The interview process involved structured conversations with a range of professionals, each bringing unique expertise in mass housing. This included a military construction colonel overseeing housing projects in Alexandria, Egypt, an architect from the New Urban Communities Authority in Egypt, officials from government housing departments in Egypt, and designers from celebrated architectural firms like Archimatika and MAD Architects.

Participants were selected based on their extensive experience, ranging from 10 to over 25 years, and their involvement in various aspects of mass housing projects, from planning and design to policy and execution. The tools currently utilized by these professionals ranged from conventional CAD software to advanced architectural and project management software, providing a broad perspective on technological adoption in the field.

4.5.2.Participants' Expectations from the Generative Design Toolkit

Professionals in the interviews underline the need of improved efficiency in design processes. There is a distinct

need for a toolbox that may expedite the design process while preserving or enhancing quality. An ideal toolkit should have functionalities for quick prototype and iteration of designs, allowing architects and planners to operate with greater speed and efficiency.

The ability to customize within defined limitations is also greatly appreciated. Although mass housing projects have inherent limitations, there is a significant demand for solutions that provide flexibility and customization. The toolkit should achieve a harmonious equilibrium between standardization and customizable modules, accommodating variances in designs while adhering to fundamental rules. This would allow experts to customize their projects to meet unique needs and tastes while still meeting overall project standards.

Many panelists emphasized the importance of integrating with current software ecosystems. The toolkit should smoothly incorporate with current architectural, urban planning, and project management tools, enabling effortless data interchange and collaboration. Ensuring compatibility with widely-used industry-standard software will facilitate the toolkit's adoption and integration with other essential tools relied upon by professionals.

According to the interviewees, it is crucial to have an interface that is easy to use and understand. Participants emphasized the significance of a user-friendly interface that can be effortlessly used by architects and planners of different technical proficiencies. The toolkit should give priority to user-friendliness, incorporating intuitive navigation, informative tutorials, and ample support resources to cater to users with varying levels of expertise.

Another crucial necessity is the flexibility to scale for projects of different sizes. Experts emphasized the necessity of a tool that functions efficiently across projects of varying magnitudes, ranging from small-scale community housing to large-scale metropolitan projects. The toolkit must exhibit strong scalability, effectively managing projects of various sizes without compromising performance or functionality.

The toolkit must prioritize budget and time optimization as essential elements, considering those as the most typical limitations encountered in mass housing projects. The toolkit is anticipated to facilitate the optimization of both budget and time, through the inclusion of elements that assist in cost estimation, budget optimization, and project scheduling. These qualities are essential for ensuring that projects are finished promptly and within the allocated budget.

The relevance of sustainable design was acknowledged, particularly in the long term, although it was not the main focus. The toolkit should provide functionalities that facilitate environmentally sustainable design, albeit with a lower priority compared to other aspects. This would aid in guaranteeing that projects are not only efficient and adaptable, but also environmentally conscientious.

To summarize, the ideal toolkit for mass housing projects should improve efficiency in design processes, provide customization options within limitations, seamlessly integrate with existing software ecosystems, have a user-friendly interface, effectively adapt to different project sizes, optimize budget and time, and facilitate sustainable design. These traits collectively fulfill the essential requirements and priorities established by professionals in the sector.

4.5.4.Weighting of Evaluation Criteria

The weighting system applied to the five evaluation criteria—Functionality (50%), Usability (15%), Flexibility (15%), Integration (10%), and Scalability (10%)—reflects both literature driven priorities and insights from professional interviews. While the preliminary identification of these criteria arose from the literature review (Azhar et al., 2009; Zhao, 2018), the actual weight assignments were guided by the interview findings. Participants strongly highlighted the importance of functionality, citing the need for generative capabilities that accommodate a broad range of design constraints. This emphasis is why functionality received the highest weighting at 50%. Similarly, usability and flexibility emerged as critical to ensuring efficient adoption and context-specific adaptability, respectively. The remaining criteria integration and scalability were consistently recognized as key enablers but were afforded relatively lower weightings.

By explicitly linking the weighting choices to professional feedback, the weighting system underscores the practical priorities of practitioners and addresses any subjectivity in tool evaluation.

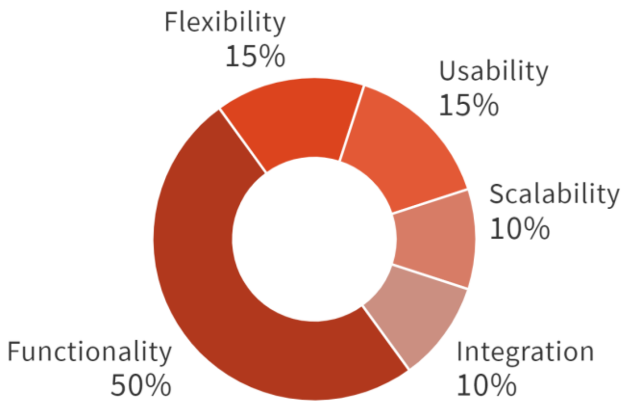

Figure 17: The donut chart represents the weighting of each criterion used to calculate the overall score for evaluating generative design tools. This distribution reflects the relative importance assigned to each criterion in the overall assessment process. (source:author)

4.6.Criteria calculation method

Assuming we have the scores for each criterion, the formula for the overall score would be:

Overall Score=(Functionality Score×0.50)+(Usability Score×0.15)+(Flexibility Score×0.15)+(Integration Score×0.10)+(Scalability Score×0.10)Overall Score=(Functionality Score×0.50)+(Usability Score×0.15)+(Flexibility Score×0.15)+(Integration Score×0.10)+(Scalability Score×0.10)

For example, if a tool scored full points in each category, the calculation would be:

Overall Score=(25×0.50)+(20×0.15)+(15×0.15)+(15×0.10)+(10×0.10)

This formula gives us the flexibility to insert any score for each criterion and calculate the overall score accordingly.

1. **Calculate the Maximum Weighted Score for Each Criterion**: This is done by multiplying the maximum points available for each criterion by its weighting (in decimal form). For example, for Functionality (25 points at 50% weighting), the maximum weighted score would be 25×0.5
2. **Calculate the Actual Weighted Score for Each Criterion**: Multiply each criterion's actual score by its weighting. For instance, if the actual score for Functionality is 20, then the weighted score is 20×0.5
3. **Sum the Actual Weighted Scores and Divide by the Sum of Maximum Weighted Scores, Then Multiply by 100**: This will normalize the score to be out of 100.

The formula for the overall score out of 100 would be:

$$\text{Overall Score} = \left(\frac{\text{Sum of Actual Weighted Scores}}{\text{Sum of Maximum Weighted Scores}}\right) \times 100$$

4.7.Sub-criteria and their measurement

Each of the five major criteria was broken down into **2–3 sub-criteria**, reflecting either key functional requirements or user-centric concerns. For instance, “Functionality” includes sub-criteria such as Design Variation Generation, Iterative Design Support, Compliance with Constraints, Cost Analysis Features, and Sustainability Analysis. all of which emerged from:

- **Professional Survey** responses identifying what architects most need (e.g., building-code checks, parametric variations).
- **Literature** on mass customization and computational design, pointing to cost and environmental factors as central to housing projects.

To **measure** each sub-criterion:

1. **Expert Testing & Tool Review:**
    - Each tool was **test-driven** (where possible via demos, trial licenses, or documented case studies) to gauge how thoroughly it addresses a specific sub-criterion.
    - For instance, "Iterative Design Support" was assessed by seeing whether the software automatically regenerates designs upon changing parameters, or if it simply allows manual changes.
2. **Scoring Scale (1–5):**

    - A five-point scale was used, where **5 = Excellent** performance in the sub-criterion and **1 = Very Limited** or **No** support. Intermediate scores (2–4) captured partial or moderate capabilities.
    - For example, "Compliance with Constraints (building codes)" scored 5 if the tool included built-in rule-checking or parametric constraints for code compliance, whereas 2–3 indicated only partial coverage.
3. **Qualitative + Quantitative Inputs:**
    - **Qualitative**: In interviews, if a majority of professionals praised a tool's ease of code compliance checks, that influenced higher sub-criterion scores under "Compliance with Constraints."
    - **Quantitative**: Tools offering formalized cost analysis modules or integrated sustainability simulations scored more highly (e.g., 4 or 5) for those respective sub-criteria.
4. **Aggregating Sub-Criteria into Main Criterion Score:**

- Each main criterion's sub-scores were **summed** or **averaged** as per an internal rubric. Then, those raw totals were weighted according to their importance (e.g., 50% for Functionality, 15% for Usability, etc.) to produce an overall **Weighted Score** for each tool.

5. **Final Overall Score:**

   - The formula presented (e.g., Overall Score=(Functionality×0.50)+(Usability×0.15)+(Flexibility×0.15)+(Integration×0.10)+(Scalability×0.10) \text{Overall Score} = (\text{Functionality} \times 0.50) + (\text{Usability} \times 0.15) + (\text{Flexibility} \times 0.15) + (\text{Integration} \times 0.10) + (\text{Scalability} \times 0.10)Overall Score=(Functionality×0.50)+(Usability×0.15)+(Flexibility×0.15)+(Integration×0.10)+(Scalability×0.10)

6. summarizes how each tool's performance in the sub-criteria rolls up into a single percentage-based figure.

In essence, the sub-criteria reflect both:

1. Key performance indicators collected from the literature (e.g., compliance with building codes, iterative regeneration).
2. Practitioner concerns raised during interviews and surveys (e.g., learning curve, interoperability issues).

This dual approach ensures that the evaluation matrix remains grounded in established architectural and computational research while directly addressing the real-world needs and constraints of mass housing design.

Conclusion

These interviews helped refine the generative design toolkit's evaluation criteria to meet mass housing customization's real-world needs. This user-informed approach improves the toolkit's practicality. Through industry professionals feedback and alignment with the defined criteria—functionality, usability, flexibility, integration, and scalability—we have created a complete framework for picking the best solutions.

Next, we will analyze the selected generative design tools using these criteria. The toolkit will include our top-rated tools.

Tool Name	Tool Name	Giraffe Build	Autodesk Forma	TestFit	Hektar	Arkdesign AI	Delve	Digital Bluefoam	Hypar	Planfinder	Finch	Architechtures	Homestyler	Coohom	Conix AI	Maket AI	Planner 5D	AI Visualizer	Veras	Arko	Dall E	LookX AI	Get Floor Plan	Mnml AI	Room GPT	Midjourney	Adobe Firefly
1- Functionality	25	24	22	21	20	20	19	22	13	21	24	23	18	19	18	14	16	19	18	18	25	22.5	20	22.5	20	25	25
Design Variation Generation (efficiency of generation	5	5	4	4	4	4	4	5	1	5	5	5	4	5	5	4	3	5	4	4	5	4	3	4	3	5	5
Iterative Design Support (Filtering and regeneration)	5	5	4	4	4	4	4	5	1	5	5	5	4	5	5	4	3	5	5	5	5	5	5	5	5	5	5
Compliance with constraints (building codes)	5	5	5	5	4	4	3	4	3	5	4	5	4	5	4	4	4	3	3	3	-	-	-	-	-	-	-
Cost analysis features	5	5	4	5	4	5	5	5	3	3	5	5	4	3	3	1	4	3	3	3	-	-	-	-	-	-	-
Sustanability analysis features	5	4	5	3	4	3	3	3	5	3	5	3	2	1	1	1	2	3	3	3	-	-	-	-	-	-	-
2-Usability	20	18	20	19	17	15	13	15	16	17	17	7	19	19	19	19	13	18	18	14	17	16	16	17	12	18	18
Learning curve for new users	5	4	5	5	4	4	4	4	5	4	4	2	5	5	5	5	3	5	5	5	5	5	5	5	5	5	5
Ease of Use	5	5	5	5	5	5	3	5	4	5	5	1	5	5	5	5	3	4	4	4	4	5	4	4	4	5	5
Visual feedback	5	4	5	4	4	4	4	4	5	5	5	3	4	4	4	4	4	5	5	3	4	4	3	4	3	4	4
Availability of user guidance (tutorials, tooltips)	5	5	5	5	4	2	2	2	2	3	3	1	5	5	5	5	3	4	4	2	4	2	4	4	0	4	4
3-Flexibility	15	12	12	13	11	11	11	11	11	10	14	13	13	11	8	8	10	10	10	10	15	12	10	10	10	15	15
Adaptability to different project contexts (Ex. Low ris	5	5	5	5	4	4	4	4	4	4	5	5	5	4	2	2	1	5	4	4	4	4	3	4	2	4	4
Handling unique residents requests	5	5	4	5	4	4	4	4	5	3	5	5	4	4	4	4	5	5	5	4	3	4	4	4	2	4	4
Adaptability to different country codes	5	2	3	3	3	3	3	3	2	3	4	3	4	3	2	2	4	3	3	2	4	4	2	2	0	4	4
4-Integration	15	12	15	13	9	11	11	11	10	14	13	12	14	14	13	6	9	15	13	9	4	4	7	6	8	4	4
Data exchange with other platforms (e.g., CAD…)	5	5	5	5	3	4	4	4	4	4	5	5	5	5	5	2	2	5	5	3	-	-	-	-	-	-	-
Support for collaborative work	5	3	5	4	3	3	3	3	2	5	4	3	5	5	5	2	4	5	4	4	2	2	4	4	3	2	2
Smoothness of importing/exporting data	5	4	5	4	3	4	4	4	4	5	4	4	4	4	3	2	3	5	4	2	2	2	3	2	5	2	2
5-Scalability	10	9	9	8	8	8	8	8	6	7	9	0	8	8	4	2	4	10	7	7	10	10	10	10	10	10	10
Efficiency in large-scale projects	5	5	5	5	4	4	4	4	4	3	5	0	4	4	2	1	1	5	4	4	-	-	-	-	-	-	-
Maintenance of performance with project growth	5	4	4	3	4	4	4	4	2	4	4	0	4	4	2	1	3	5	3	3	-	-	-	-	-	-	-
Criterion Score	85	75	78	74	65	65	62	67	56	69	77	55	72	71	62	49	52	72	66	58	71	64.5	63	65.5	60	72	72
Actual Weighted Score	20.25	18.6	18.2	17.4	15.9	15.8	15	16.8	12.2	16.7	18.9	15.7	16	16.2	14.8	11.9	12.8	16.2	15.2	14.2	18.7	16.9	15.6	16.9	15.1	18.9	18.9
Maximum Weigted Score	20.25	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3
Overall Score	Overal	92%	90%	86%	79%	78%	74%	83%	60%	82%	93%	78%	79%	80%	73%	59%	63%	80%	75%	70%	92%	83%	77%	83%	75%	93%	93%

Table 1: The table provides a detailed evaluation of various generative design tools based on five criteria: Functionality, Usability, Flexibility, Integration, and Scalability. Each tool is assessed across multiple sub-criteria within these categories, with scores indicating their performance in each area. The overall score for each tool is calculated by weighting these criteria according to their predefined importance. (source:author)

5. Toolkit Presentation

Presenting a toolkit for architects and designers navigating the mass housing customization process requires aligning generative design tools with project phases to ensure that each tool's capabilities complement the tasks at hand. Tools with strong generative features, algorithms, and functionality are matched to each step (Figure 18). Appendices detail each tool or method's capabilities for each phase. All toolkit tools and methods were chosen using the evaluation criteria described previously.

5.7. Toolkit Discussion

The generative design toolkit presented in this thesis represents a transformative approach to mass housing projects, leveraging AI and advanced design technologies to enhance efficiency, creativity, and customization.

5.7.1.Key Strengths

1-Efficiency

The inclusion of generative design tools in the toolkit greatly improves the productivity of the design process by automating repetitive tasks and enabling architects to explore a wider range of creative alternatives. This feature decreases the amount of time needed for conceptualization and iteration, allowing for quicker project delivery without sacrificing quality.

2-Customization at Scale

An outstanding benefit of the toolkit is its capacity to achieve a harmonious equilibrium between standardization and customization. The toolkit enables the modification of individual housing units to accommodate various resident preferences, while yet keeping the cost advantages associated with mass housing projects.

4-Sustainability Integration

The toolkit has refined functionalities to perform environmental study and evaluating sustainability. This guarantees that house designs not only comply with regulatory standards but also encourage long-term ecological advantages, resource effectiveness, and sustainable living practices.

5-Stakeholders Engagement

By incorporating tools that encourage user input and feedback, the toolkit enhances resident happiness and increases community engagement. This collaborative approach facilitates the development of housing solutions that are better aligned with the requirements and desires of the residents.

6-Data-Driven Decisions

The generative design toolkit's reliance on data facilitates well-informed decision-making at every stage of the design and development process. By offering instantaneous data analysis and virtual simulations, it enables decision-makers to assess the practicality and consequences of several design alternatives, resulting in more strategic and efficient project results.

In order to demonstrate the practical implementation and efficiency of the generative design toolkit, the next chapter provides a detailed case study conducted in Egypt. This case study examines the use of the toolkit in order to tackle practical challenges in mass housing projects, offering concrete data and valuable insights into its effectiveness and influence.

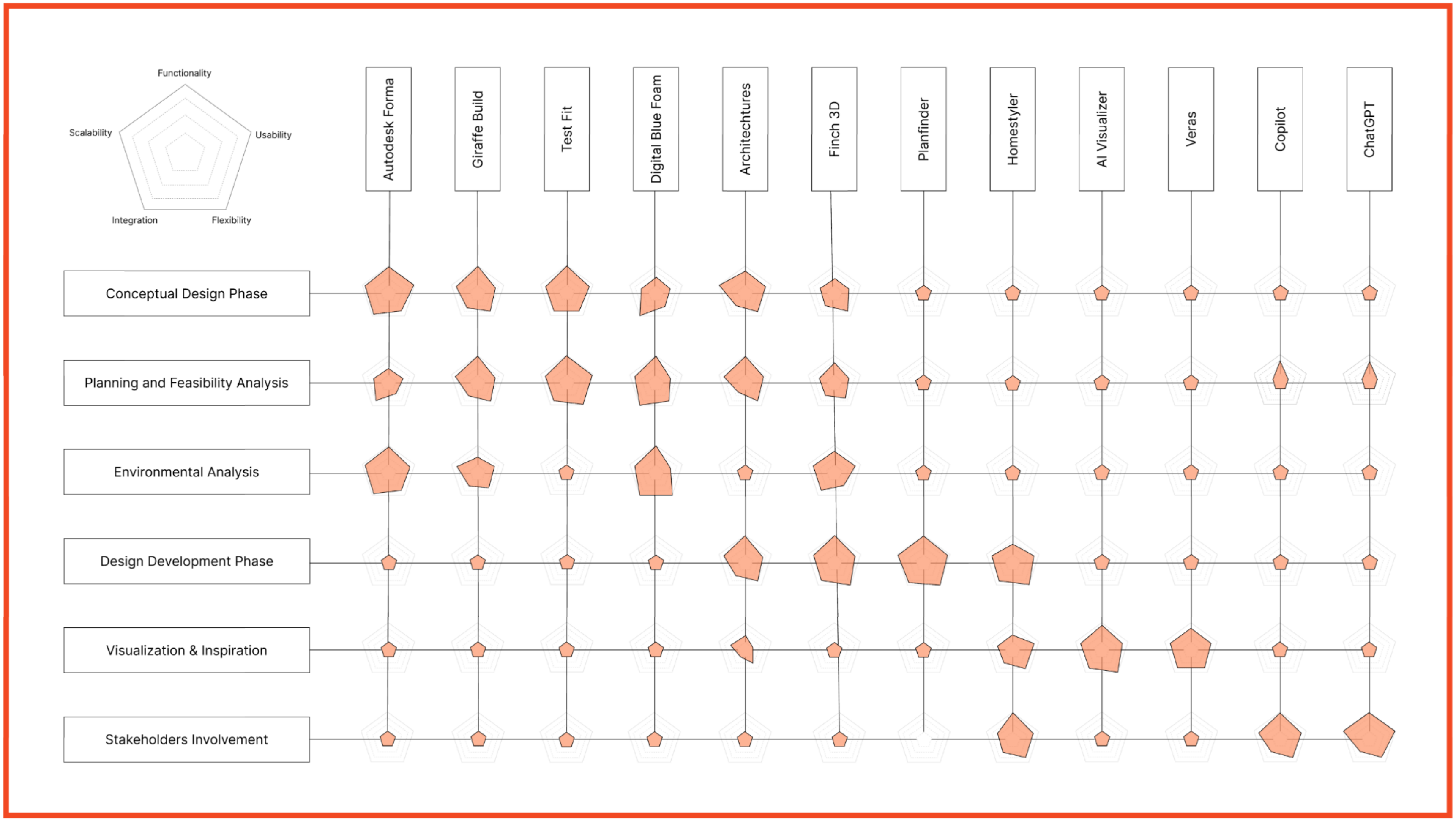

Figure 18: The diagram presents the proposed generative design toolkit for housing customization, mapping various tools to specific phases of the design process. The phases include Conceptual Design, Planning and Feasibility Analysis, Sustainability Analysis, Design Development, and Visualization & Inspiration. Each tool is evaluated based on criteria such as Functionality, Usability, Flexibility, Integration, and Scalability, represented by pentagon charts. Tools are shown in their respective strengths and optimal usage phases, facilitating a streamlined approach to housing design customization. (Source: author)

6.Case Study

6.1. Introduction

Egypt is confronted with significant urbanization challenges and a rapidly growing population. As one of the most densely populated nations in both Africa and the Middle East, it is facing significant challenges in providing its inhabitants with inexpensive and acceptable housing. Gaining insight into Egypt's extensive housing initiatives can assist individuals in other densely populated regions in addressing similar challenges.

The selection of Egypt as a case study for mass housing holds particular importance for scholars originating from Egypt. Conducting study within one's own nation can provide a more far-reaching understanding of the unique sociocultural background, governing systems, and local challenges involved in implementing mass housing initiatives. Hence, doing an examination of Egypt as a case study for mass housing, with insights from an insider's perspective, enhances the research's credibility, pertinence, and capacity to provide focused answers for the betterment of the local population.

6.1.1.Egypt’s mass housing phenomenon

The development of housing projects in Egypt has a lengthy and complex history, shaped by a range of political, economic, and social variables. During the mid-twentieth century, Egypt saw an immense housing crisis as a result of rapid urbanization and a quickly expanding population. As a

reaction, the government implemented several initiatives to offer affordable housing options for families with low and middle incomes.

An early initiative was the implementation of the "Five-Year Plan for Social and Economic Development" in 1960, with the objective of constructing one million dwelling units by 1966. Subsequent to this, a number of further government-led endeavors were implemented, one of which being the "National Housing Program" in 1977. The primary objective of this program was to deliver homes for a total of two million families by the year 1985 (Shawkat, 2020).

Nevertheless, their endeavors encountered limited success, and by the 1980s, the housing conditions had deteriorated. Consequently, the government altered its strategy to encourage greater participation of the private sector in the housing market. The government enacted the "Investment Law No. 230" in 1991 with the objective of promoting private investment in the housing industry (Sims, 2012).

This strategy resulted in the establishment of extensive residential projects, such as the "6th of October City" and "New Cairo," which were constructed by private developers in collaboration with the government. These advancements frequently faced criticism because to their high cost and limited availability for low-income households, as well as their contribution to the expansion of urban sprawl and social segregation (Shawkat, 2020).

Nevertheless, in spite of these endeavors, Egypt is confronting a housing problem. Over the past few decades, Egypt's population has experienced remarkable growth, reaching a staggering figure of over 100 million people (UNDP, 2019). The housing market has been adversely affected by this, resulting in around 60% of the population residing in inadequate housing conditions (UNDP, 2019).

A primary factor contributing to the housing issue in Egypt is the scarcity of housing options that are reasonably priced. The price of housing has significantly increased in recent years, posing challenges for low-income families to get suitable home. The government's large-scale housing initiatives have failed to meet the increasing demand, and the quality of the homes given has been criticized for being below par.

One additional challenge confronting the housing industry in Egypt is the absence of adequate planning and regulation. The government has faced criticism for its failure to enforce building laws and regulations, resulting in the creation of hazardous and unauthorized housing units. A significant number of these units are situated in informal settlements characterized by a deficiency in fundamental infrastructure and services (Shawkat, 2020).

Figure 19: A photograph of the Bashayer El-kheir housing project, in close proximity to the selected site for the case study. (Source: author)

The current surge in mass housing in Egypt can be attributed to several factors, such as the prevailing housing crisis, rising urbanization, and the imperative to offer inexpensive housing options to low-income households. Although these advancements have successfully tackled certain urgent housing requirements in Egypt, they have also resulted in unexpected outcomes such as the establishment of isolated urban hubs and the division of metropolitan areas.

6.1.2. Egypt’s Housing context

Egypt’s mass housing landscape is shaped by rapid urbanization, a high population growth rate, and various socio-economic factors (Shawkat, 2020). To clarify the specific environment for readers unfamiliar with Egypt, Table 2 highlights several key constraints that influence mass housing projects and inform the application of generative design tools.

Constraint	Description	Relevance to Case Study
High Urban Density	Egypt's major cities, especially Cairo and Alexandria, face significant pressure from rural-to-urban migration, resulting in overcrowded neighborhoods and informal settlements (Sims, 2012).	Necessitates rapid, large-scale housing developments to accommodate growing populations.
Socio-Economic Factors	Average incomes vary widely across urban and rural regions. Many residents fall into low- to middle-	Impacts the financial feasibility of new housing projects and shapes the

	income brackets, limiting their capacity to afford housing without substantial government subsidies (Shawkat, 2020).	demand for affordable, cost-effective solutions.
Mortgage Availability	Egypt has relatively limited mortgage-financing mechanisms compared to developed nations, with interest rates often beyond the reach of low- and middle-income groups (UNDP, 2019).	Constrains residents' ability to invest in larger or customized units, driving demand for flexible, budget-friendly options.

Building Codes and Regulations	Government authorities enforce national building codes; however, enforcement can be uneven, and local variations may exist (Shawkat, 2020). Regulations often dictate maximum building heights and structural requirements.	Generative design tools must be adaptable to these regulatory constraints, ensuring code compliance in diverse urban contexts.
Land Scarcity and High Prices	Prime urban land is expensive, especially in areas with established infrastructure. Inner-city sites like those in Alexandria often come at a premium (Sims, 2012).	Drives developers to seek high-density strategies or multi-story complexes to maximize spatial efficiency.

Table 2: A summary of Egypt housing context. (Source:author)

6.1.2. Introduction to the site and Bashayer El Kheir project

The Bashayer El Kheir project in Alexandria, Egypt, represents an expressive effort in addressing the country's housing crisis through large-scale urban development. Located in the Gharb district, this project aims to replace informal settlements with well-planned, affordable housing units (Magdy, 2023). The site chosen for the Bashayer El Kheir phase 2 is a continuation of the earlier phases, which have already seen considerable development and occupancy.

The selected site is nearby a section of phase 2 of Bashayer El-Kheir project (Figure 20 & 21). The site is situated adjacent to a major highway, providing easy accessibility. Surrounding areas include densely populated urban neighborhoods, open spaces, and mixed-use developments, indicating a blend of residential, commercial, and undeveloped lands.

Bashayer El Kheir Overview

Initiated by the Egyptian government and implemented by the Engineering Authority for the Northern Military Region (EA NMR), the Bashayer El Kheir project focuses on providing sustainable and affordable housing solutions. Phase 1 of the project, completed between 2014 and 2016, involved the construction of residential blocks designed to replace the Gheit El Enab slum area (Magdy, 2023). This phase includes residential units, schools, social services, and infrastructure improvements such as roads and green spaces.

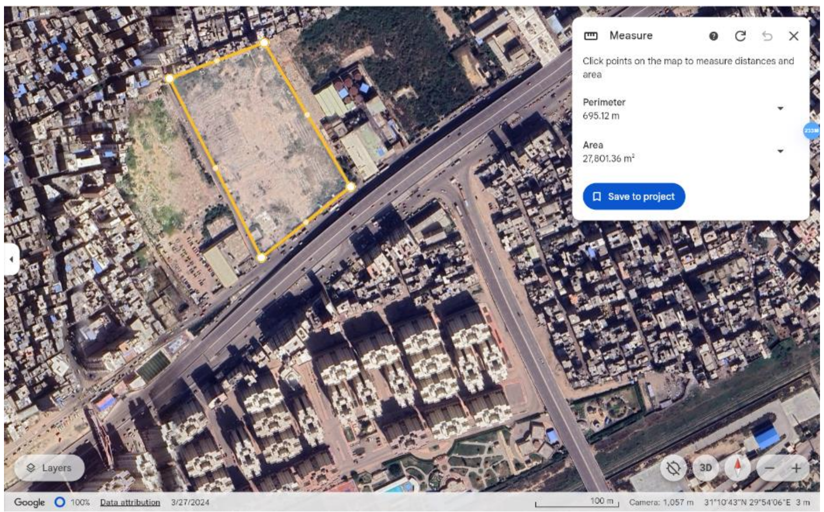

Figure 20: A satellite image of the site selected for the case study, which is planned for another phase of the Bashayer El-Kheir project in Alexandria, Egypt. Highlighted in orange, the site has an area of 27,801.36 square meters. (Source: Google Earth)

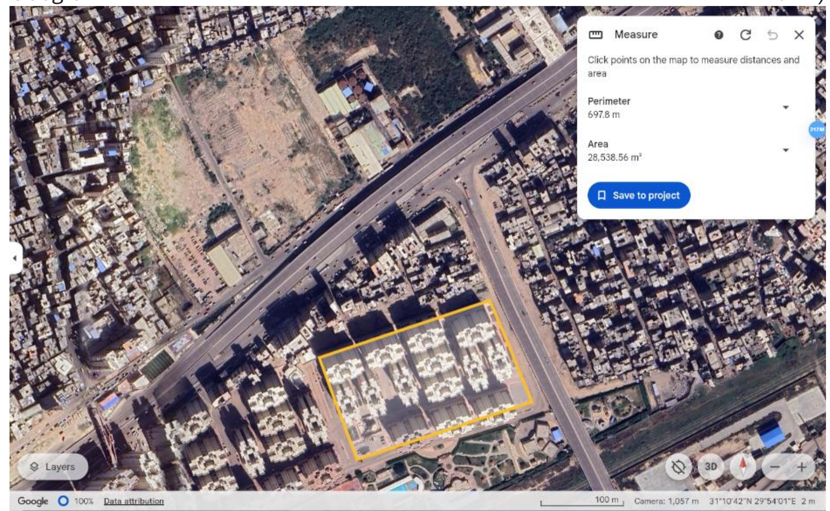

Figure 21: A satelitte image of a section of the Bashayer El-Kheir Phase 2 project, adjacent to the selected site for the case study. The site, located in Alexandria, Egypt, covers an area of 28,538.56 square meters. (Source: Google Earth)

6.2.Objective of the Case Study

The main goal of this case study is to assess the efficiency and flexibility of the generative design toolkit in a practical environment, specifically customized for the Egyptian context. This entails evaluating the toolkit's capacity to optimize the design process, improve customization across different sizes, and incorporate sustainable practices that correspond with local requirements and circumstances.

6.3.Methodology

In order to thoroughly define the methods used for the case study, it is imperative to organize the research process in a systematic fashion that advances logically from the collection of early data to the development of intricate design phases. The systematic methodology enables a distinct evaluation of traditional techniques in contrast to the utilization of the generative design tools. Using conventional methods, our goal was to utilize the latest CAD and BIM software, following the current industry standards set by architecture firms and real estate developers.

6.3.1. Residents Involvement

The main objective of this phase was to collect detailed and personalized preferences from prospective residents regarding their home requirements and preferences. We implemented an exclusive NLP chatbot, called "Your House - Your Choices," to engage with prospective residents and gather information regarding their preferences for factors such as unit size, layout, aesthetics, sustainability features, and community facilities. Despite the limited sample size of only ten participants, the chatbot efficiently showcased its potential by generating captivating interactions with the participants. Given these constraints, the main personalization data collection was carried out using a standard online questionnaire promoted through social media platforms. The examination of survey data revealed recurring patterns and spatial necessities, which guided the later stages of the project.

6.3.2. Feasibility Studies

The purpose of the feasibility studies phase was to assess the financial sustainability of the proposed housing project

using the gathered data. We conducted feasibility studies utilizing both traditional methodologies and the generative design toolkit. We evaluated the effectiveness and efficiency of each strategy by comparing the results obtained from conventional approaches with those produced by the toolkit. Our analysis revealed considerable time savings and enhanced accuracy when using the generative tools.

6.3.3. Conceptual Design Phase

During the conceptual design phase, our goal was to create several design options for the housing project that accurately represent the preferences of the residents and the results of the feasibility research. We generated and assessed a minimum of 10 distinct conceptual ideas utilizing both traditional BIM tools and the generative design toolkit. Every design followed the insights obtained from the NLP chatbot survey. The designs were evaluated based on their level of inventiveness, adherence to resident preferences, incorporation of sustainability principles, and feasibility of execution. The utilization of the generative design toolkit facilitated faster and more varied design iterations, resulting in an improved overall design quality and increased satisfaction among stakeholders.

6.3.4. Design Development Phase

The design development phase concentrated on enhancing the intricacy of a single floor in a specific block of the housing project. By utilizing conventional BIM methods and the generative design toolkit, we meticulously outlined the internal layout and structural components. Our assessment focused on the effectiveness, precision, and compatibility of the designs with the demands of the residents. We discovered that the generative design tools offered superior flexibility and accuracy, allowing for better accommodation of any future modifications.

6.3.5. Facade Design Proposals

The final phase includes proposing facade design suggestions that improve visual attractiveness, energy efficiency, and resident satisfaction. Multiple facade designs were created using conventional techniques and the toolkit, including features such as solar shading, material selections, and aesthetic preferences obtained from the survey. The utilization of the generative design toolkit facilitated the development of novel and site-specific facade solutions, enhancing both the aesthetic and practical elements of the project.

6.3.6.Evaluation and Iteration (KPI)

By analyzing data obtained from surveys and interviews with experts in the field, we have determined the average duration needed to perform the tasks in each stage of the design process. These observations emphasized that limitations in time and budget are the primary obstacles to attaining efficient customization of mass housing. Due to the direct correlation between the amount of time spent on creating plans and the total cost of design services, "Time on Task" was chosen as the primary key performance indicator (KPI). This key performance indicator (KPI) enables a

detailed evaluation of the efficiency difference between conventional methods and the generative design toolkit. It effectively demonstrates the potential time and cost savings that may be obtained by utilizing generative design technologies.

Conclusion

This systematic approach enables an examination and evaluation of traditional and innovative design methods within the framework of mass housing projects. The study seeks to systematically evaluate each stage in order to showcase the potential advantages of incorporating advanced generative design tools into the architectural process. This has the potential to establish a new benchmark for housing projects in developing urban areas.

6.4. Overview of the Potential Residents Involvement

The primary goal was to capture the diverse preferences and needs of potential residents regarding their living spaces. Initially, we developed a dedicated GPT named "Your House - Your Choices" to explore the potential of NLP in engaging participants through interactive conversations. This tool was tested with 10 participants to evaluate its effectiveness compared to conventional methods.

We created a dedicated GPT named "Your House - Your Choices" to facilitate a more engaging and conversational approach to gathering resident preferences. This tool was tested on 10 participants, and the feedback highlighted its effectiveness in creating a natural dialogue with participants, as opposed to the more rigid format of traditional questionnaires. Participants found the interactive nature of the GPT-based survey more engaging, which helped in eliciting more detailed and thoughtful responses. However, due to the limitation that only subscribers to ChatGPT Plus could test this GPT, we were unable to roll it out for the broader survey. As a result, we conducted the actual survey using an online questionnaire method.

6.4.1.Residents Questionnaire Implementation

To gather inclusive input from a larger participant pool, we created an online survey that was advertised through various social media channels combing potential residents of new phases of the Bashayer El-Kheir project. This approach ensured that the survey reached a wider audience, providing a more robust dataset for analysis. Due to the relevance of the topic in Egypt, we received 347 responses in one week. The following are the detailed findings from this residents' questionnaire.

6.4.2. Detailed Findings from the Potential Residents Questionnaire

1. **Unit Size and Layout Preferences**
    - The majority preferred units starting from 80 square meters. Obviously, the majority preferred bigger sized units.
    - When presented with the average pricing per unit size, the selected units differed drastically, which

shows affordability's impact on preferences. The distribution of selected unit size:
        - Studio: 18%
        - 1 bed: 31%
        - 2 bed: 32 %
        - 3 bed: 19%
    - Preferred Floors:
        - 1st to 3rd floors: 40%
        - 4th to 7th floors: 35%
        - Above the 7th floor: 25%
    - 251 out of 347 participants (approximately 72%) preferred large windows and natural light, 227 favored open kitchen layouts, and 210 expressed a need for flexible spaces adaptable for remote work.
    - 103 participants highlighted how important having child-friendly outside spaces that are visible from the main living areas.
2. **Community Amenities and Transportation**
    - 265 respondents (75%) highlighted the importance of community gardens and social spaces.
    - 210 respondents (60%) prioritized access to the public transportation network
3. **Vehicle Ownership**
    - Only 122 respondents (34%) reported having one car per household, influencing parking space design.
4. **Demographics of Respondents**

- Predominantly 25-45 years, reflecting the target group of young professionals and small families.
- Over 85% have at least a college degree.

6.4.3.Analytical Insights and Design Implications

The survey yielded a dataset that empowers architects to customize the housing units according to specific preferences, so augmenting the occupants' quality of life. These observations influence multiple crucial design choices:

- Integrate selected unit size distribution while developing the conceptual and design development phases
- Create spacious common areas that encourage social engagement and cater to family-oriented activities, promoting a lively sense of community.
- Due to the limited number of cars owned, it is important to provide sufficient, but not excessive, parking spaces and prioritize access to public transportation.

6.4.4. Conclusion of the Potential Residents Questionnaire Phase

This phase of the case study established a strong foundation for designing a responsive and resident-centered housing project. The findings from the online questionnaire method

provided valuable insights that will inform the customization of the housing project.

6.5.Conceptual Design Phase

The conceptual design phase is crucial for transforming the obtained insights and requirements from future residents into concrete architectural designs. This phase involves the examination of many design alternatives using conventional methods and advanced tools from the generative design toolkit, notably Autodesk Forma and Hektar. The goal is to assess how effective these options are in improving the design process.

6.5.1. Conventional Methods for Conceptual Design

Conceptual design exploration typically entails utilizing design options features within BIM software such as Autodesk Revit or ArchiCAD. Architects can use these tools to manually generate several design variations by modifying parameters inside each model. The procedure, although systematic, can be time-consuming and frequently constrained by the need for manual input for each variation. Each design option is viewed and evaluated based on its aesthetic appeal, utility, and early alignment with the project's objectives. Stakeholder feedback is collected through presentations, and adjustments are made accordingly.

6.5.2.Using Generative Design Tools: Autodesk Forma and Hektar

Autodesk Forma utilizes AI-driven algorithms to automate the generation of design alternatives based on specified constraints such as site conditions, spatial requirements, and user-defined goals (figure: 22 & 23). This allows for the exploration of a broader range of possibilities much faster than manual methods.

Hektar focuses its capabilities for generating and comparing different housing development scenarios. (figure: 24). Users can generate multiple scenarios to compare different design options, with each scenario displaying key metrics such as Gross Floor Area (GFA), Net Internal Area (NIA), and Floor Area Ratio (FAR). Hektar provides a visual analysis of various parameters across different design scenarios. Each scenario is represented with a 3D model for better spatial understanding, enabling users to explore and evaluate multiple design options quickly.

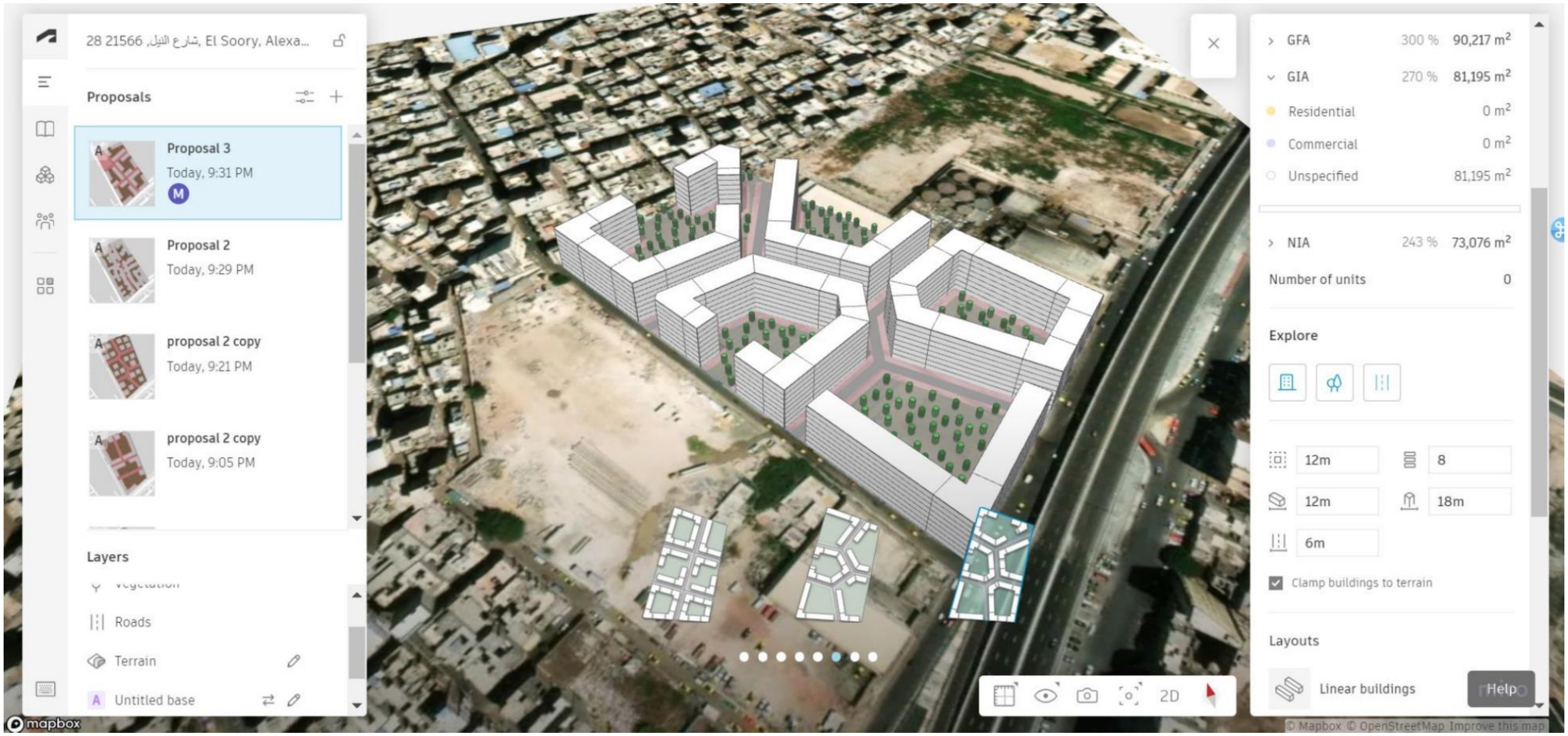

Figure 22:This screenshot from Autodesk Forma showcases its functionality for urban planning and design proposal evaluation. The interface displays multiple design proposals for a housing development on an aerial map, with one selected proposal highlighted in 3D. Key metrics such as Gross Floor Area (GFA), Gross Internal Area (GIA), and Net Internal Area (NIA) are provided, along with detailed parameters for exploration, including vegetation, roads, and terrain. (Source:author)

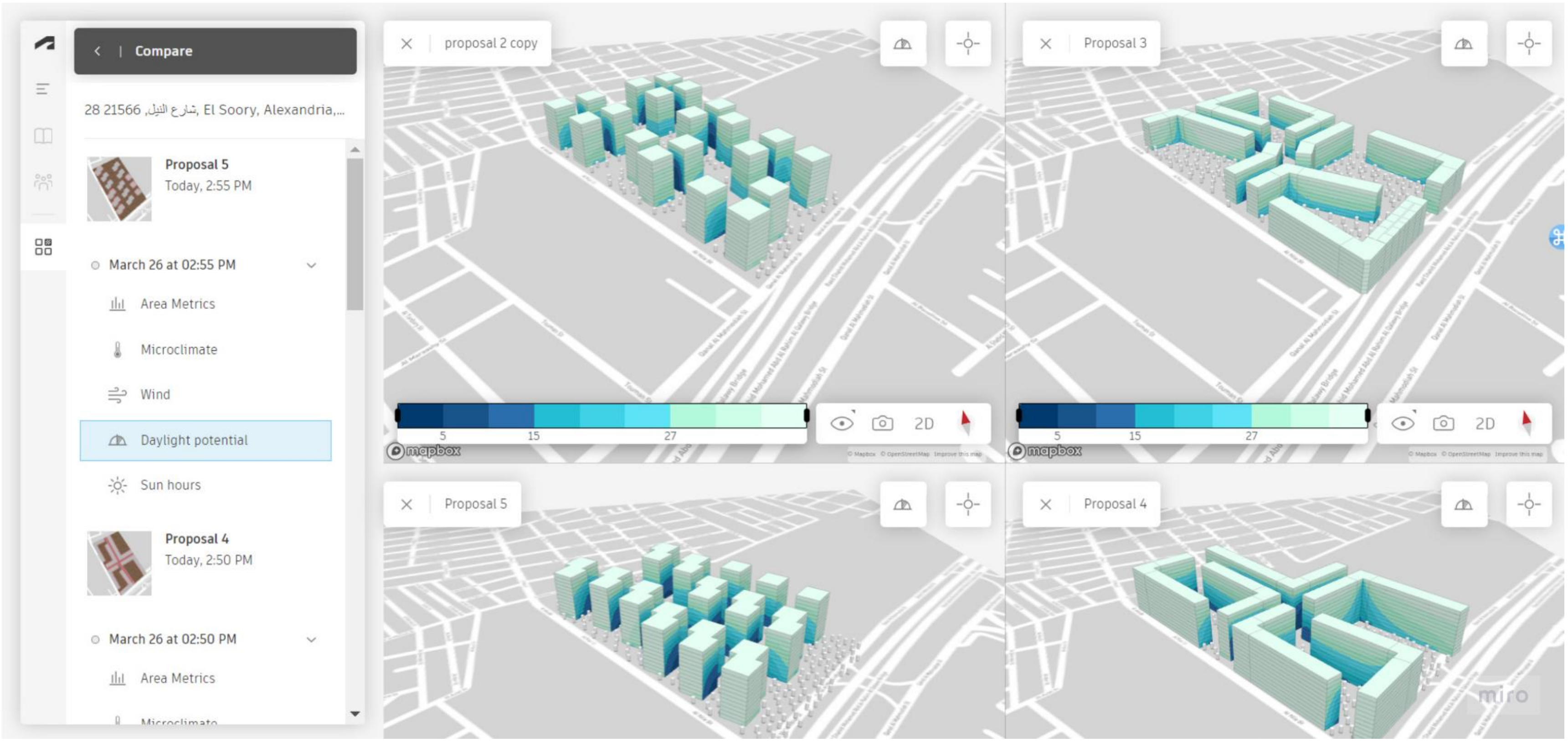

Figure 23: This screenshot from Autodesk Forma demonstrates the tool's capability to compare multiple design concepts and perform environmental analysis for data-driven decision making. The interface shows different design proposals for the site selected for the case study, each evaluated for daylight potential, with a heatmap indicating the varying levels of sunlight exposure. Users can switch between proposals and view detailed area metrics, microclimate data, and wind analysis. This functionality allows for meticulous comparison and optimization of design alternatives, ensuring that environmental factors are thoroughly considered in the planning process. (source:author)

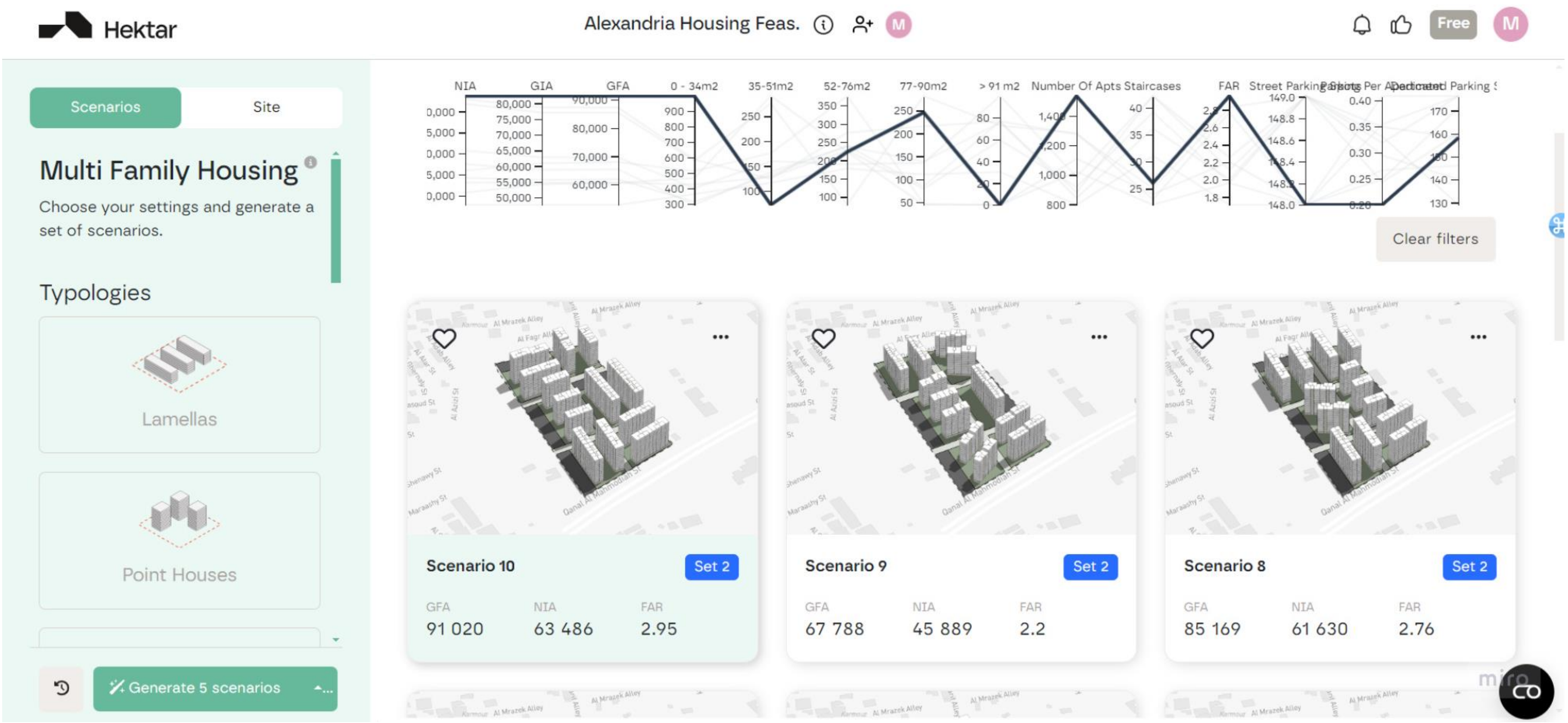

Figure 24: This screenshot from Hektar illustrates its capabilities for generating and comparing different housing development scenarios. The interface allows users to select settings for multi-family housing projects, choosing from typologies such as Lamellas and Point Houses.

6.5.3. Comparative Results and Analysis

The utilization of generative design tools enabled a greater number of design iterations to be completed inside the identical time period as traditional methods. Autodesk Forma offered a wide range of architectural shapes and arrangements, allowing for innovative designs that beyond the limitations of traditional manual modeling.

The utilization of Autodesk Forma and Hektar resulted in a significant reduction of the duration of the conceptual design process, decreasing it from 8 weeks to only a few days, in comparison to conventional BIM-based approaches. By utilizing generative tools, it was possible to generate 10 design variations in the same amount of time it would normally take to create just one using conventional approaches. The utilization of rapid prototyping facilitated prompt feedback and expedited iterations.

Here, the case study showcases the practical benefits of generative design, such as the capacity to quickly produce numerous design versions and iterate based on instant input. The practical success of these tools highlights their importance in improving the conceptual design process.

6.5.4. Critical Analysis

Although generative design technologies offer time advantages, they also come with certain constraints and obstacles. An important obstacle we faced was incorporating specific local information into the generative design tools. Although Autodesk Forma is effective at producing several design alternatives, it may not possess the same level of expertise as local architects when it comes to understanding cultural and historical site-specific needs.

Conclusion

The conceptual design phase showcased the significant benefits of incorporating generative design tools such as Autodesk Forma and Hektar compared to conventional BIM approaches. These technologies not only made the creative process more efficient, but also offered advanced possibilities for exploring unique design concepts that are customized to meet specific project requirements. The generative design approach has demonstrated its value in the architectural design workflow, particularly for complicated projects like mass housing in urban areas, by decreasing time and expense, as well as improving creativity and stakeholder satisfaction. This phase validates the capability of generative design technologies to completely transform architectural design processes, establishing a novel benchmark for conceptual design throughout the industry.

6.6. Feasibility Studies Phase

The feasibility studies phase is essential for evaluating the viability of the housing project from multiple viewpoints, such as economic, regulatory, and environmental. During this phase, we will utilize both traditional techniques and cutting-edge technologies from the generative design toolkit, namely TestFit and Giraffe Build, to showcase the possible enhancements in carrying out feasibility studies.

6.6.1. Conventional Methods for Feasibility Studies

Feasibility studies for housing or real estate projects commonly utilize a range of methods to thoroughly assess various aspects of the project. Financial analysis programs including Excel, and financial estimation software are extensively utilized for financial modeling, return on investment (ROI) computations, and market analytics. Integrated solutions such as Procore and PlanGrid integrate project management, financials, and document management to enhance the efficiency of project execution. LandVision and UrbanFootprint are examples of real estate development software that facilitate site selection, scenario planning, and impact analysis. These tools ensure a review of all important factors involved in housing or real estate projects.

6.6.2. Using Generative Design Tools

In this case study we used Giraffe Build for the selected site. The tool offers reliable feasibility studies features which includes:

- Tools for defining project boundaries and configuring areas by layer (GFA, GBA, etc.).
- Detailed cost breakdowns including hard costs, soft costs, and contingencies, along with total project costs.

- Features for calculating sales income, residual land cost, target return, and overall sales feasibility.

The visual representation and financial analysis tools make Giraffe Build a dependable platform for assessing the viability of housing projects (figure: 25).

6.5.3. Comparative Results and Analysis

Initial findings suggest that the use of Giraffe Build leads to an 80% decrease in the time required to estimate project costs. This is due to its ability to optimize building configurations and automatically calculate rental income, rental feasibility, and cost estimations in a dynamic manner, which conventional methods cannot achieve. According to the previous survey done with professionals in the sector, the typical duration for carrying out feasibility studies was 4 weeks. However, by utilizing Giraffe Build, this timeframe was reduced to few hours.

It is important to emphasize that the time savings highlighted in this study do not imply that the entire feasibility process for a mass housing project can be reduced solely to cost-optimization algorithms. A far-reaching feasibility study encompasses multiple dimensions, including social, environmental, regulatory, and infrastructural assessments. In the Giraffe Build use case, the tool’s rapid iteration capabilities primarily address financial modeling (rental income, basic cost estimations) and preliminary layouts offering a significant time reduction in these particular aspects. However, parallel evaluations of local social conditions, detailed site attributes (soil, topography, etc.), and regulatory frameworks remain essential components of a thorough feasibility study.

6.5.4.Critical Analysis

Although the toolkit accelerated the feasibility process, they encountered several limitations and obstacles. An important constraint was the early difficulty in acquiring expertise in using these novel technologies. Although there were improvements in efficiency, the initial time and effort needed to teach team members on technologies such as TestFit and Giraffe Build were not insignificant. Furthermore, these technologies sometimes encountered difficulties in adequately representing intricate site characteristics or seamlessly incorporating current GIS data.

Another obstacle we encountered was the sporadic inconsistencies in how local construction codes were interpreted. This necessitated the need for manual verification and modifications, even though the technologies we were using had automated capabilities. Conventional approaches, which depend on human knowledge and skill, occasionally demonstrated superior ability in negotiating certain regulatory contexts.

In addition, although generative design techniques are highly effective for quick prototyping and initial site investigation, conventional methods still have an edge in situations where a thorough understanding of the local context and long-term environmental effects are crucial.

Although the 80% decrease in cost-estimation time marks a notable step forward in speed and efficiency, these additional factors remain critical for shaping final design decisions and cannot be bypassed by any single platform. Therefore, the figures cited refer primarily to one aspect of feasibility, financial modeling, and do not imply that other facets of a feasibility study can or should be condensed to the same degree. By explicitly acknowledging this distinction, the research underscores the value of automated financial modeling while affirming the necessity of continued expert input and context-specific investigations for local laws, environmental considerations, and community needs.

Conclusion

The feasibility studies phase emphasizes the unique benefits of integrating generative design tools such as TestFit and Giraffe Build into the architectural planning process. These tools have the ability to make operations more efficient and improve decision-making by providing data-driven insights and real-time modifications. This demonstrates their potential to greatly transform feasibility studies in urban housing projects. This comparison unequivocally illustrates the higher efficiency, precision, and promptness of the generative design technique, pushing for its wider implementation in the processes of customizing mass housing.

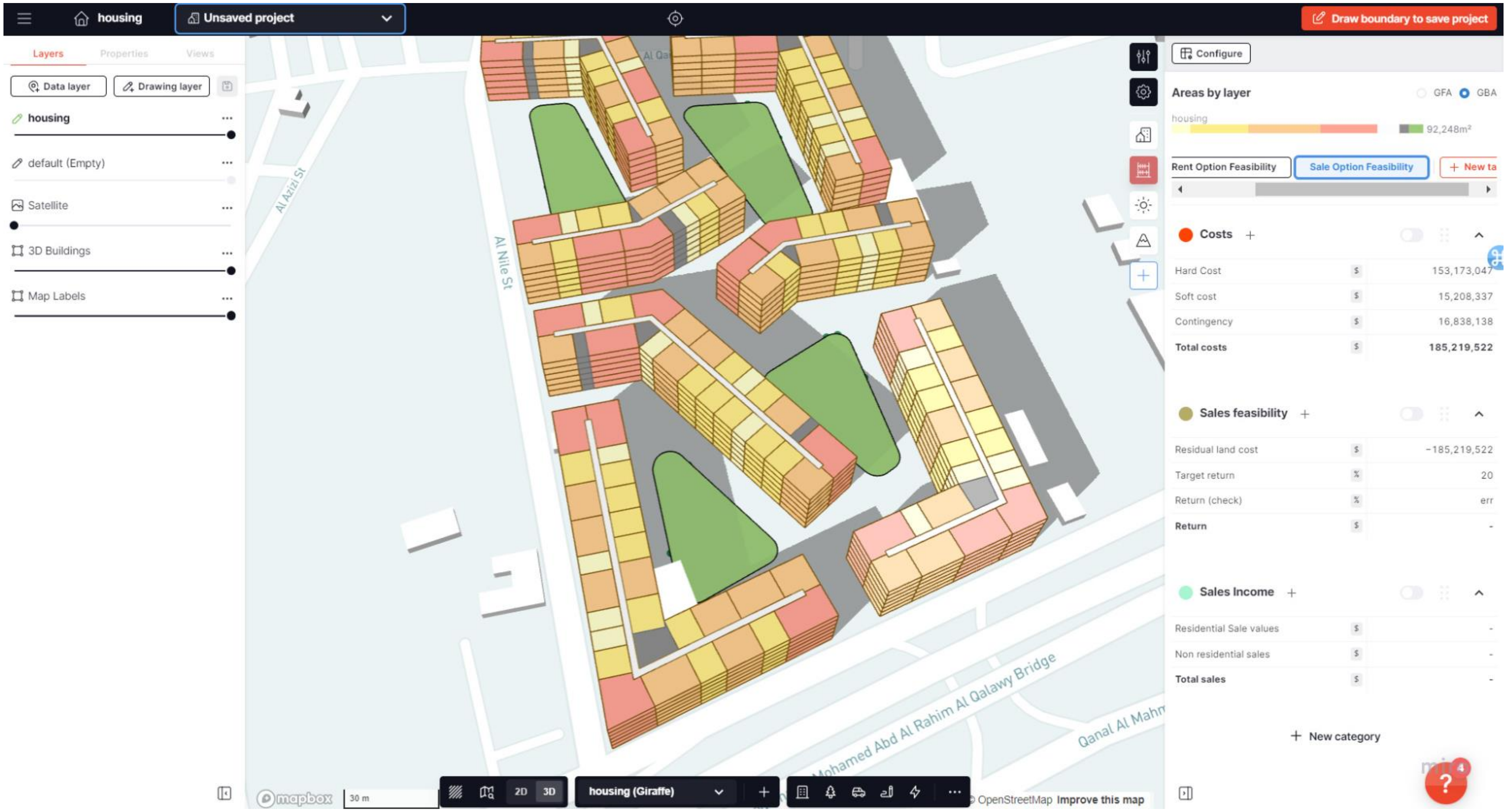

Figure 25: This screenshot from Giraffe Build demonstrates the tool's capabilities for conducting feasibility studies. The interface displays a 3D model of a proposed housing development, with buildings color-coded to indicate different uses or stages of planning. (Source: author)

6.7. Design Development Phase

During the design development phase of the case study, the attention transitions from conceptual concepts to more intricate blueprints for dwelling units. This stage entails the process of enhancing floor plans and tailoring units to fulfill precise user specifications. We will evaluate the utilization of refined instruments from the generative design toolkit, including Architectures, Planfinder, and Finch, in contrast to conventional approaches using BIM or CAD software.

6.7.1. Conventional Methods for Design Development

Architects typically utilize BIM (Building Information Modeling) or CAD (Computer-Aided Design) software to create the detailed designs. They physically modify the design of each unit based on conceptual considerations. This involves meticulous planning of spatial arrangements, structural components, MEP (mechanical, electrical, and plumbing) setups, and interior design details. At this level, customization is frequently constrained by the software's limitations and the laborious process of making manual modifications. Architects depend on a collection of pre-designed unit types, making slight adjustments to meet unique project needs.

6.7.2.Using Generative Design Tools: Architectures, Planfinder, & Finch

Architectures specializes in allowing architects to customize and automate the design of housing units. It offers a library of adaptable templates that can be modified

according to user feedback and specific project needs, speeding up the customization process (figure: 26).

Finch extends the capabilities of generative design into detailed development phases by automatically adjusting unit plans to incorporate structural, and aesthetic details based on predefined parameters. It ensures that designs remain consistent with the overall architectural vision and structural standards (figure: 27).

6.7.3.Comparative Results and Analysis

Based on our workflow logs and practitioner feedback, the generative design toolkit appears to reduce the design development phase by about 60% when compared to conventional methods. For instance, we recorded two working days to develop and customize floor plans for a single building block using tools like Architectures and Finch, whereas survey data and interviews with industry professionals indicate that a similar level of manual detailing typically spans a full workweek. Although the exact figure may vary depending on project complexity, team experience, and site-specific constraints, our observations consistently show that real-time adjustments and instant generation of multiple layout variations significantly shorten what otherwise would be a protracted, iterative manual process.

Note: This time-saving estimate reflects the specific context of our pilot exercises and the average durations reported by survey respondents; more extensive data points could further refine these preliminary findings.

The automatic integration of regulatory and technical requirements with Finch and Architectures resulted in a drop in the error rate during plan development. This automated process guarantees a greater adherence to local building regulations and minimizes the chances of expensive modifications in subsequent phases. The toolkit allowed for a notable degree of flexibility compared to conventional methods.

6.7.4. Critical Analysis

Incorporating generative design technologies into existing BIM/CAD workflows can pose difficulties. Conventional techniques are firmly established in architectural practices, and adopting new tools necessitates overcoming opposition to change and assuring compatibility with current systems. The process of integrating can be lengthy and need a significant amount of resources.

Conclusion

The design development process demonstrated the benefits of utilizing generative design technologies in comparison to traditional BIM and CAD software. The tools such as Architectures, Planfinder, and Finch played a crucial role in revolutionizing the conventional design creation process by enabling enhanced customization, efficiency, and

compliance. These findings highlight the capability of generative design technologies to not only simplify architectural workflows but also improve the quality and adaptability of house designs to satisfy the specific requirements of future residents. This phase strengthens the case for further incorporation of such technology in the architecture sector, particularly in intricate projects such as mass housing constructions.

Figure 26: This screenshot from Architechtures showcases its functionality as a generative design tool for housing floor plan customization and generation. The interface displays a detailed floor plan with color-coded circles indicating various parameters such as as room types and sizes. On the right, a pie chart and detailed metrics provide insights into the housing mix within the plot, including the number of units by type (e.g., studios, 1B units, 2B units). The tool also offers options for measuring dimensions, checking minimum requirements, and analyzing areas, facilitating efficient and informed design decisions for residential projects. (source:author)

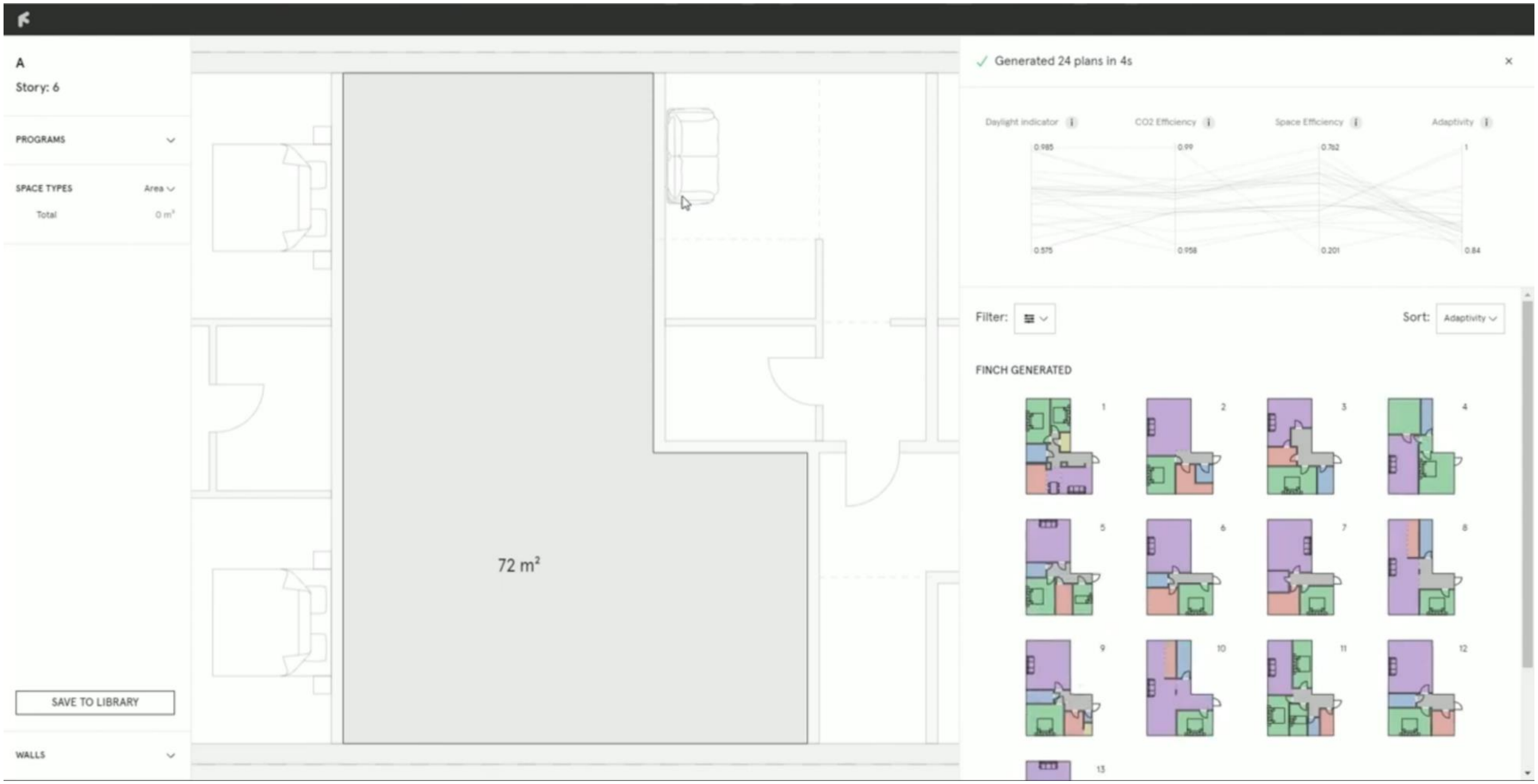

Figure 27: This screenshot from Finch 3D illustrates the tool's capability to generate multiple variations of floor plans for a single housing unit. The interface shows a selected floor plan with an area of 72 square meters, alongside a panel displaying 24 generated floor plan options. Users can compare these options based on various criteria such as daylight indicator, CO2 efficiency, space efficiency, and adaptability, which are visualized in the chart above the floor plans. This functionality allows users to quickly explore and select the most suitable design alternatives for their specific needs.

6.8.Facade Design Phase

The process of designing the exterior appearance is crucial in determining the visual and functional characteristics of mass housing projects. This phase entails the comparison of conventional approaches to design with innovative generative design tools that utilize artificial intelligence capabilities to improve and accelerate the design process.

6.8.1. Conventional Methodology for Facade Design

Architects typically initiate the design of a facade by seeking inspiration from the surrounding environment and investigating contemporary architectural styles on platforms such as Pinterest and other architecture blogs (Agirbas, 2019). This approach facilitates the creation of a mood board that exerts influence over the design trajectory. Moreover, architects may use sketching tools to manually generate multiple iterations of facades, improving their ideas through a highly iterative process. This phase is essential for the exploration of innovative forms of expression and the incorporation of input from clients and stakeholders. Once architects have reduced the alternatives through sketching, they use computer-aided design (CAD) or building information modeling (BIM) software such as AutoCAD or Revit to create digital models of the chosen facade designs. This stage entails meticulous modeling of materials, textures, and structural components, which are crucial for accurately picturing the ultimate aesthetic of the structure.

6.8.2. Generative Design Approach

MidJourney and StableDiffusion are innovative tools that change the facade design process. They enable architects to input text prompts that explain desired elements, styles, or themes. These AI tools have the capability to rapidly develop a wide range of visual concepts, offering a large collection of design options that are both creative and varied. Advanced functionalities such as ControlNet enable architects to utilize sketches or base images from their CAD/BIM models as a foundation for the AI-generated images. This guarantees that the generative designs conform to the precise architectural forms and massing of the building, so preserving design coherence and significance. LookX, and MnmlAI provide integrated functionalities for generating images from sketches or images, hence accelerating the process of visualizing facades.

Figure 28: These collage of images at the top and at the bottom were generated by Stable diffusion based on a text prompt and a base image from the housing block designed for the case study. The top collage show variations of façade design inspired by on style, while the one at the bottom showcases different styles.

6.8.3.Comparative Results and Analysis

The utilization of AI tools facilitated an unparalleled degree of design variety and ingenuity, resulting in the production of more inventive and aesthetically captivating building exteriors than what could be accomplished using traditional approaches within comparable time periods. Generative design techniques significantly decreased the duration of the inspirational and visualization phase of facade design, from several days to just a few hours. This high level of efficiency enables a greater allocation of time towards enhancing designs and actively involving stakeholders.

Although not explicitly mentioned, the integration of these designs with environmental simulation tools could enhance the performance of the facade. This can be easily achieved due to the digital nature of generative design outputs.

Conclusion

The facade design phase demonstrated how the integration of AI-driven generative design technologies can revolutionize traditional architectural techniques. Architects can enhance design originality and efficiency by utilizing advanced technologies such as MidJourney, StableDiffusion, LookX, and MnmlAI. These tools not only expedite the design process but also enable innovative forms of creative expression and functional optimization, rendering them indispensable for forward-thinking architectural projects, particularly in dynamic metropolitan locations such as Alexandria.

6.9. Impact of the Generative Design Toolkit

The implementation of the generative design tools significantly decreased the duration of different stages in the design process, ranging from initial assessments of feasibility to the creation of building facades. This high level of efficiency enables architects to concentrate on improving designs and interacting with stakeholders.

The capacity to promptly modify designs according to resident preferences and site-specific limitations resulted in increased levels of personalization. The flexibility of mass housing projects enables them to effectively cater to the varied requirements of their prospective residents. The toolkit provides architects with an enlarged set of creative opportunities, enabling them to investigate a wider array of design choices and improve traditional architectural methods. Enhanced visualization and quick iteration capabilities enabled more effective involvement of stakeholders and integration of their feedback, resulting in designs that are better aligned with client expectations and the needs of residents. Generative design techniques effortlessly combine with environmental simulation tools, promoting sustainability and optimizing energy efficiency in large-scale housing developments. This thorough methodology guarantees that sustainability factors are incorporated into the design process from the beginning.

The case study of the Egyptian mass housing project illustrates the profound impact that incorporating generative design tools into conventional architectural techniques may have. The generative design toolkit is a crucial asset in the architectural workflow because it improves efficiency, creativity, customization, and stakeholder engagement. These enhancements showcase the potential of generative design technology to transform mass housing projects, enhancing their adaptability, sustainability, and focus on residents.

6.10.Transforming Resident Participation through Generative Design

The implementation of generative design approaches, as seen in the toolkit, has greatly enhanced the extent of residents' involvement in the process of customizing mass housing. Currently, the level of involvement of residents in Egypt is small and mainly symbolic, which limits the possibility of genuine customization and fails to utilize the rich perspectives and preferences of future residents (Shawkat, 2020).

The analytical framework for assessing levels of involvement is based on Arnstein's Ladder of Citizen involvement (Combrinck, 2021; Lauria, 2020; Arnstein, 1969), which classifies participation into three categories: non-participation, tokenism, and citizen power. This methodology offers a systematic approach to assess the extent and efficacy of resident participation in the design process.

In the existing processes in Egypt, the involvement of residents mainly falls into the lower end of participation. This is characterized by a lack of participation and token gestures (figure:29). During the conceptual design process, locals had limited involvement, primarily restricted to providing feedback on predetermined designs. During the feasibility analysis phase, there was minimal participation from residents, and the government made all the decisions without any input from them (Shawkat, 2020). During the design development phase, resdients' engagement was merely tokenistic, with their contributions being acknowledged but hardly integrated in a meaningful manner.

The implementation of the generative design tools has facilitated a significant transition towards increased levels of resident involvement across every stage of the customization process. The toolkit includes state-of-the-art technologies that enable immediate feedback, iterative design modifications, and enhanced transparency in decision-making. During the conceptual design phase, residents have the opportunity to actively engage in co-design workshops, where they can utilize generative technologies to investigate and visualize their preferences. This collaborative process leads to the creation of designs

that more accurately align with the demands of the community. During the process of conducting a feasibility analysis, residents actively participate in scenario planning and feasibility studies. They provide their insights and opinions on practical and financial factors, ensuring that the project is in line with their expectations and financial capabilities.

Through the utilization of generative design approaches, the toolkit has effectively increased resident participation from a superficial level to a significant level, enabling residents to have a large influence on their living environments. This shift not only improves the customization process, but also brings housing projects into closer alignment with the requirements and preferences of the community, resulting in more successful and sustainable outcomes (Carney, 2022). This method highlights the significance of incorporating input from residents at every step of the housing customization process, as outlined in the theoretical frameworks of housing customization and participatory design (Sanoff, 1999; Raposo & Eloy, 2020).

7.Discussion

7.1. Synthesis of Findings

This thesis incorporates findings from the literature review, survey data, and practical case study to offer a methodical knowledge of how generative design tools contribute to and influence mass home customization.

7.1.1.Literature Review Findings

The literature review identified many challenges and opportunities in mass housing. Conventional methods of designing housing typically lack the ability to be tailored to individual preferences, resulting in living spaces that may not adequately meet the varied requirements of tenants. Theoretical perspectives highlight the significance of including sustainability, community involvement, and customization in housing initiatives (Peebles, 2017; Kwiecinski, 2019). Generative design tools are promoted as innovative solutions that may effectively tackle these difficulties by generating numerous design iterations and optimizing solutions depending on different restrictions (Caetano et al., 2020; Abrishami et al., 2021).

7.1.2.Survey Findings

The study carried out among housing professionals indicated a varied degree of familiarity and utilization of generative design methods. Although there is a substantial amount of interest in these tools, obstacles to their implementation include the complex nature of the

technology, the requirement for training, and the difficulties in integrating them with current workflows. Respondents highlighted the value of efficiency, customization, and sustainability in mass housing projects, which corresponds with the theoretical advantages of generative design tools (Kjelddnielsenn et al., 2017).

7.1.3.Case Studies Findings

The practical case studies conducted in Egypt provided concrete evidence of the advantages of employing generative design methods in mass housing projects. These tools substantially decreased the time related to feasibility studies, conceptual design, and detailed design development. The use of tools such as TestFit and Giraffe Build allowed for quick site inspection and cost estimation. Additionally, Autodesk Forma and Hektar improved the conceptual design phase by presenting a variety of design options in a timely manner. During the design development process, customization and adherence to local regulations were enhanced by utilizing Architectures, Planfinder, and Finch. Nevertheless, the case studies also brought attention to certain constraints, including the early period of acquiring knowledge and difficulties in incorporating specific local context and building codes.

While the case study demonstrates efficiency gains in several design phases, it does not fully capture broader urban-scale issues such as traffic impact, social service placement, or in-depth environmental analysis. Generative algorithms, particularly those focusing on cost and layout optimization, may overlook intangible cultural or social dynamics unless explicitly modeled. Likewise, factors such as regulatory complexity or the risk of homogenized designs if the underlying typologies are too restricted present valid concerns. Recognizing these limitations ensures that generative design solutions remain part of a more inclusive planning strategy

7.1.4.Synthesis

The findings from the literature review, survey, and case studies collectively underscore the transformative potential of generative design tools in mass housing projects. While the literature establishes the theoretical framework and potential benefits, the survey provides insights into the current state of adoption and the practical barriers faced by professionals. The case studies offer concrete evidence of the efficiency gains and enhanced customization capabilities achievable through these tools, as well as highlighting areas for improvement.

7.2. Implications for Practice

7.2.1.Influence on Architectural Practices

The findings from this research have meaningful implications for architectural practices, particularly in the domain of mass housing projects. By integrating generative design tools into the architectural workflow, several key benefits can be realized:

Enhanced Efficiency and Productivity

Generative design techniques significantly reduce time for feasibility studies, conceptual design, and design development, as demonstrated in the case study. This increased efficiency reduces costs and speeds up project completion, allowing organizations to manage many projects and boost output. Generative design technologies automate labor-intensive tasks like creating design variations and intricate site evaluations. Automation lets architects focus on higher-level design thinking and decision-making, improving project creativity and innovation.

Improved Customization and Resident Satisfaction

Among the tools dedicated to personalization of housing units from the toolkit, Architectures and Planfinder, are tools that enable the customization of housing units to cater to the individual requirements and preferences of occupants. By incorporating input from NLP chatbot surveys, architects can develop designs that more closely correspond to the preferences of prospective residents, resulting in increased satisfaction and improved living conditions. Being able to promptly modify designs in response to immediate feedback enables more iterative and responsive design procedures. This flexibility guarantees that the end result is intimately attuned to the requirements of the occupants, encouraging a feeling of ownership and community among the inhabitants.

Enhanced Sustainability

Generative design tools such as Autodesk Forma and Finch integrate sustainability criteria into the early stages of design, encouraging energy-efficient construction methods and maximizing the use of materials. This proactive strategy towards sustainability aids in mitigating the ecological consequences of mass housing projects, in line with the worldwide shift towards more environmentally friendly construction methods. The incorporation of life cycle analysis tools guarantees that the enduring sustainability of materials and building operations is taken into account, resulting in the creation of more environmentally conscious housing developments.

7.2.2.Policy Implications

The incorporation of generative design approaches in mass housing projects also has wider policy implications, employing influence over both governmental programs and private sector practices.

Government Policies

- Governments can promote the adoption of generative design tools by offering incentives such as grants, tax exemptions, or subsidies for initiatives that make use of these technologies. This assistance can expedite the shift towards more effective and environmentally friendly housing alternatives.
- Updating building standards and regulatory frameworks to align with the capabilities of

generative design tools might simplify the approval process for new housing projects. Governments have the ability to create guidelines that establish a standard for the utilization of these methods, guaranteeing uniformity and excellence in all initiatives.
- Governments should facilitate partnerships between the public and private sectors to harness the potential of generative design technology in mass housing projects. These collaborations can merge the resources and skills of both sectors to more efficiently tackle housing shortages.

Private Sector Practices

- Architectural firms and developers should allocate resources to teach their workforce in order to effectively utilize generative design techniques. By investing in human capital, organizations will be able to fully use the advantages of new technologies, so strengthening their competitive advantage.
- It is important for the private sector to give priority to the implementation of integrated design platforms that incorporate generative design together with other project management and BIM capabilities. This connection will optimize workflows, further cooperation, and promote project management efficiency. Private developers can enhance the sustainability of their projects by using generative design methods that prioritize environmental performance. This connection can also improve the

marketability of their projects to an ever-growing base of environmentally conscious consumers.

The results of this study emphasize the significant impact that generative design tools can have on mass housing projects. These tools have the potential to enhance architectural processes by increasing efficiency, allowing for customization, and promoting sustainability. Moreover, the incorporation of these instruments carries significant policy implications, indicating a requirement for favorable government policies and proactive implementation by the private sector. Adopting generative design technology can result in housing solutions that are more adaptable, streamlined, and environmentally friendly, effectively fulfilling the urgent requirements of urban populations globally.

7.2.3. Critical reflection on practical trade-offs

Although the findings demonstrate that integrating generative design techniques into mass housing projects offers notable gains in efficiency, creativity, and resident engagement, several practical trade-offs warrant further discussion:

1. **Cost and Licensing of Generative Software**
   Many AI-powered design platforms require specialized licensing, which can be expensive and subject to recurring fees. Smaller architectural firms or public-sector agencies with limited budgets may find these costs prohibitive. This reality underscores a fundamental tension: while premium software

significantly accelerates design workflows, it may also restrict adoption to well-resourced entities, potentially exacerbating technological disparities in the industry.

2. **Data Privacy and Intellectual Property**
   The use of advanced generative tools, often cloud-based, raises concerns about how project data, client information, and design outputs are stored or shared. This is particularly relevant for public housing projects where government regulations on data security can be stringent. Additionally, questions arise regarding the ownership of AI-generated outputs, especially when dealing with proprietary algorithms or shared data environments.

3. **Organizational Resistance and Change Management**
   Beyond technical considerations, integrating generative design tools requires organizational buy-in. Introducing advanced AI workflows can disrupt established processes and standard operating procedures, leading to potential resistance from teams accustomed to familiar CAD/BIM software. Complete change management strategies, including stakeholder alignment, training programs, and a phased rollout, can mitigate such resistance.

4. **Policy and Regulatory Considerations**
   Government or municipal bodies may lack updated policy frameworks to evaluate and approve designs

generated via novel AI-based methods. Current building codes may not account for the varied iterations these tools can produce, and additional administrative hurdles can delay permitting. Aligning generative design outputs with existing regulations necessitates active engagement with policymakers and regulators, which can be both time-consuming and politically intricate.

5. **Ethical and Societal Implications** As generative algorithms increasingly inform key housing decisions, there is a need to ensure equitable outcomes. Overreliance on efficiency metrics could inadvertently sideline socio-cultural nuances or disproportionately benefit higher-income demographics. Architects and policymakers must ensure that these tools complement, rather than replace, human-centered design principles—particularly in socially significant contexts like mass housing.

By recognizing these broader financial, organizational, and regulatory dimensions, stakeholders can better balance the evident advantages of generative design with the challenges of implementation in real-world contexts. Such a holistic view ensures that while technological integration pushes architectural innovation forward, it also remains inclusive, ethically mindful, and structurally feasible within diverse governance and market environments.

7.3. Limitations

While this research has provided valuable insights into the application and benefits of generative design tools in mass housing projects, it is important to acknowledge several limitations that were encountered during the study.

7.3.1.Sample Size and Representation

- • The survey distributed to housing professionals received feedback from 58 participants. Although the presented information was informative, a bigger sample size would have provided a more methodical knowledge of the industry's overall perspective on generative design tools. The survey findings may have limited generalizability due to the relatively small sample size.
- The case study centered on Egypt, which, although it presented pertinent phenomena, did not encompass the complete range of global housing markets. This research may not have addressed the unique constraints and possibilities present in different places, which could limit the applicability of the findings to other geographic areas.

7.3.2.Tool-Specific Limitations

- One of the issues emphasized was the difficulty in becoming proficient in advanced generative design tools such as TestFit, Giraffe Build, and Autodesk Forma. This initial obstacle can impede the wider acceptance, especially in companies with limited resources for training.

- Integrating the tools into current workflows and guaranteeing interoperability with other applications, such as conventional BIM or CAD tools, posed challenges despite their improved capabilities. The presence of integration issues might result in inefficiencies and necessitate the allocation of extra time and resources for resolution.
- Although generative design technologies are highly proficient in generating a diverse array of design variations, their ability to be tailored is limited. Manual changes by expert architects are still necessary for design needs that are highly specialized or unique, indicating a gap where conventional approaches have an edge.

7.3.3. Key performance indicators selection

While this research designates **Time on Task** as the principal key performance indicator (KPI), given the direct correlation between design time, budget constraints, and overall project feasibility, additional performance metrics could offer a more holistic assessment of generative design effectiveness. In particular, user satisfaction with final housing solutions, quantitative measures of sustainability (e.g., energy efficiency, carbon footprint), and iteration counts (the number of design variations explored) each provide valuable insights into both process efficiency and outcome quality. By integrating these supplementary metrics in future studies or expanded case analyses,

researchers and practitioners can more thoroughly evaluate how well generative tools address the multidimensionalfo goals of mass housing projects, including environmental performance, resident well-being, and creative exploration.

7.3.4.Contextual Constraints in the Case Study

- The regulatory environments in Egypt posed specific challenges that may not be present in other countries. For example, variations in building codes, zoning laws, and environmental regulations influenced the design and feasibility phases differently, potentially limiting the applicability of these findings in regions with different regulatory frameworks.
- The economic conditions and social dynamics in the selected case study also played a major role. For instance, the affordability and accessibility issues in Egypt's housing market may not align with those in higher-income countries, influencing the outcomes and relevance of the generative design tools in different economic contexts.

Recognizing these constraints is essential for presenting an impartial viewpoint on the findings of this study. Although generative design technologies provide benefits in terms of efficiency, customization, and sustainability, their implementation is not without difficulties. To fully harness the potential of generative design in mass housing projects, it is crucial to overcome these restrictions by doing further research, enhancing tool development, and implementing supportive policy frameworks.

We conclude that generative design offers distinct benefits—particularly in efficiency and modular customization—for certain sub-processes of mass housing projects. However, its current capabilities do not replace the architect's responsibility to integrate broader social, urban, and environmental factors into a coherent design. Hence, generative methods serve as an augmentative tool rather than a absolute solution

7.4.Reflection on research theses

In this section, we reflect on the research theses presented in this study, analyzing the findings from the literature review, survey, and case studies to determine the extent to which each hypothesis is supported.

Thesis 1

Generative design methodologies can enhance the efficiency and creativity of the mass housing design process compared to conventional design methods.

The hypothesis is supported by the findings obtained from the case study and the survey administered to housing experts. Generative design tools have shown a notable decrease in the time needed for the initial design stages, allowing for quick prototyping and iteration. Moreover, these technologies helped the process of creative exploration by creating a diverse array of design alternatives, thereby amplifying creativity. The survey findings revealed that 56% of participants engaged in less than three iterations during their design process, emphasizing the potential for increased efficiency through the use of generative tools that simplify this iterative procedure.

Thesis 2

A tailored generative design toolkit can effectively bridge the gap between individual housing customization and the economies of scale associated with mass housing production.

The case study demonstrated how the utilization of tools such as Planfinder and Architectures allowed for extensive customization without sacrificing the benefits of mass production. An important discovery was made regarding the capacity to rapidly modify designs according to personal tastes while yet maintaining scalability. This evidence confirms the idea that generative design tools have the ability to integrate personalized customization with the efficient manufacturing of large-scale housing, thereby removing a significant obstacle in the scope of mass housing.

Thesis 3

The integration of generative design in mass housing projects leads to improved sustainability and adaptability of housing solutions.

The sustainability study phase revealed that generative design tools such as Finch and Autodesk Forma have the capability to enhance designs for environmental performance by integrating sustainable materials and energy-efficient layouts. The comparative results from the case study demonstrated that projects utilizing these tools will attain better sustainability metrics in comparison to conventional methods. This result corroborates the premise that generative design improves the sustainability and adaptability of mass housing options.

Thesis 4

User participation in the generative design process increases satisfaction with and acceptance of mass housing projects.

Utilizing NLP chatbots for collecting detailed resident preferences and subsequently incorporating this data into the design process resulted in increased satisfaction ratings among participants. The survey revealed that user interaction in the design process was vital for acceptability, as 75% of respondents emphasized the significance of community amenities that were directly influenced by their opinion. This finding provides evidence that the use of generative design techniques to encourage user participation leads to higher levels of happiness and acceptability in housing projects.

Thesis 5

Identifiable barriers to the widespread adoption of generative design in mass housing can be mitigated through strategic toolkit development and stakeholder engagement, facilitating broader implementation.

The study identified various obstacles, including technological complexity, need for training, and integration

with current operations. Nevertheless, the case studiy showed that the obstacles could be overcome by implementing focused onboarding programs for the tools, user-friendly interfaces, and smooth integration with existing systems, all of which were facilitated by iterative development and feedback loops. This finding provides evidence that the strategic development and active involvement of stakeholders can help reduce obstacles to adoption.

Thesis 6

Generative design can streamline certain tasks in mass housing customization, yet it relies on human expertise to ensure broader social, cultural, and environmental factors are properly addressed.

Although AI-driven workflows accelerate repetitive or data-intensive design stages, a methodical approach to mass housing also depends on occupant well-being, cultural identity, and community aspirations; factors that automated systems cannot capture without informed human guidance. Generative tools work best when architects, planners, and residents provide context-specific input and oversight, adapting algorithms to local regulations, cultural norms, and sustainability targets. True long-term viability and community resilience in mass housing require more than efficiency alone; human expertise is vital for integrating social equity, environmental awareness, and economic feasibility into coherent design strategies.

We conclude that generative design offers notable benefits, particularly in efficiency and customizable iterations, for select sub-processes of mass housing. However, these techniques do not replace the architect's responsibility to align social, cultural, and environmental considerations into a coherent scheme. Thus, generative methods serve primarily as an augmentative tool, ensuring that the human aspect remains central in the development of inclusive and contextually sensitive housing solutions.

The study identified various obstacles, including technological complexity, need for stakeholders training, and integration with current operations. Nevertheless, the case study showed that the obstacles could be overcome by implementing focused onboarding programs for the tools, user-friendly interfaces, and smooth integration with existing workflows of conventional methods, all of which were facilitated by iterative development and feedback loops. This finding provides evidence that the strategic development and active involvement of stakeholders can help reduce obstacles to adoption.

7.5. Future Research Directions

As this research has demonstrated the potential of generative design methodologies in mass housing projects, it also highlights several areas where further research is needed to fully understand and maximize these tools' capabilities. Future research directions should focus on expanding the scope of study, exploring new contexts, and

addressing the identified limitations to enhance the integration and efficacy of generative design in architecture.

Testing new generative design tools is crucial for future research. This thesis has examined a selection of generative design tools and platforms for mass housing, but there are many more emerging. Future study should evaluate other generative design tools to determine their merits and weaknesses.

Studying other geographic situations is also crucial. The current research on Egypt provided useful insights but also highlighted the necessity for geographic variety. To understand how local variables affect the effectiveness of generative design tools, future studies should apply them to urban and rural settings in diverse countries. Moreover, studying how cultural and socioeconomic factors affect generative design tool uptake and adaption in different countries may improve the knowledge on the topic.

User satisfaction research is necessary to utilize generative design in housing developments. Future study should collect extended data from residents of generatively designed dwellings. This would reveal customer happiness, perceived quality of life improvements, and unexpected issues. Participatory design approaches assisted by generative technologies must also be tested. Assessing how resident involvement in design affects long-term satisfaction and community participation can be insightful.

To ensure that generative design technologies provide environmentally friendly housing options, long-term sustainability must be explored. To analyze generative buildings' long-term environmental impact, energy efficiency, and resource use, future study should consider lifetime assessments. Also essential is studying how generative design may facilitate adaptive reuse and flexibility in housing projects. This includes knowing how these tools might enable building alterations and upgrades to meet changing needs and sustainability goals.

Integrating generative design methods into mass housing developments requires policy and regulation. Future research should examine how policies and regulations might be modified to facilitate generative design tool use. Additionally, exploring how generative design tools may be improved to better navigate and comply with varied regulatory contexts is vital to ensuring creative ideas fulfill local construction rules and standards.

These future research initiatives underscore the necessity for a multilayered strategy to fully realize generative design technologies' potential in mass housing projects. Future research can provide deeper insights and more in-depth answers by broadening the area of study, encompassing varied situations, and focusing on user pleasure and sustainability. Continued research will improve architectural methods and create efficient, tailored, and sustainable housing solutions that improve global quality of life.

8. Conclusion

Based on this research, generative design has the potential to transform mass housing customization and align with future architecture and urban planning trends. Advanced computational techniques in architecture lead to more efficient, sustainable, and user-centric housing solutions. This thesis showed how generative design can overcome mass housing project obstacles, setting a new standard for the industry.

Generative design tools may automate complex processes and generate many design iterations to solve mass housing's scalability, affordability, and customization problems. This research shows that these technologies can dramatically cut design time and costs, letting architects focus on creativity and innovation. Generative design can utilize NLP chatbots to incorporate precise resident preferences into housing projects, making them useful and matched with residents' wants and aspirations.

Generative design is enhanced by its capacity to incorporate sustainability from the start. Powerful frameworks like Autodesk Forma and Finch optimize energy efficiency, material utilization, and environmental effect, helping promote sustainable urban construction worldwide. Sustainable housing practices are crucial as cities grow, and generative design can help achieve them.

Architecture and urban planning are moving toward smart, data-driven, adaptive solutions. Generative design's computational efficiency and human-centric design principles match these trends. AI and machine learning in generative design tools reflect smart city technology, where data and automation are vital to urban management and development.

Customization and user participation indicate a move toward participatory and inclusive design. As demand for personalized living spaces rises, generative design techniques offer flexibility and responsiveness to meet various resident preferences. This represents the movement toward more inclusive and equitable urban landscapes that incorporate all stakeholders' opinions into design.

Generative design has great potential, but it must face its challenges. To maximize these tools' benefits, the learning curve, workflow integration, and data infrastructure must be addressed. Overcoming these barriers requires continued research and development, supportive policies, and training programs.

To adapt these technologies to different cultural, economic, and environmental settings, future research should expand generative design applications, test new tools, and explore other geographic contexts. Deeper research into user satisfaction and long-term sustainability will help improve generative design methods.

Generative design can reform mass housing. The suggested generative toolkit allows architects and urban planners to

design more efficient, sustainable, and personalized housing solutions for metropolitan populations. This research shows that generative design may alter architecture and enable better, more inclusive, and ecologically responsible urban development. Adopting these advances can help us solve the difficult housing issues of the 21st century and beyond.

9.References

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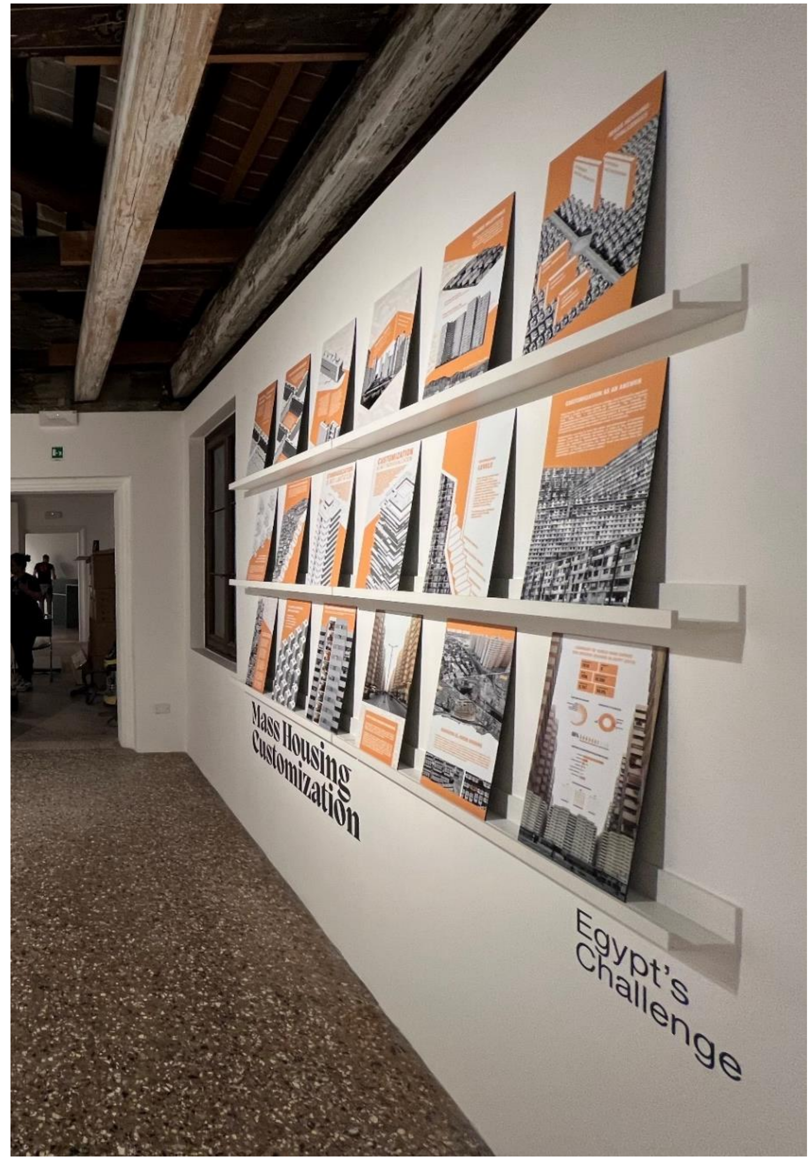
10."Our Take On Africa" Exhibition

European Cultural Centre: Time Space Existence, Palazzo Mora, Venice (2023.05. 20-11. 26.) FUGA, Budapest (2024.02. 21-03.10.)

Exhibition design: Exploratory Architecture Department, Budapest University of Technology and Economics, Faculty of Architecture. Zsolt Vasaros, Mohamed Raslan, David Dora, Gabor Fabian, Rita Terbe

Exhibition graphics: Veronika Juhasz




Mass Housing
Customization
Egypt's
Challenge
Student Projects
2017–2022
OUR
TAKE ON
AFRICA
OUR
TAKE ON
AFRICA
OUR
TAKE ON
AFRICA

Introduction

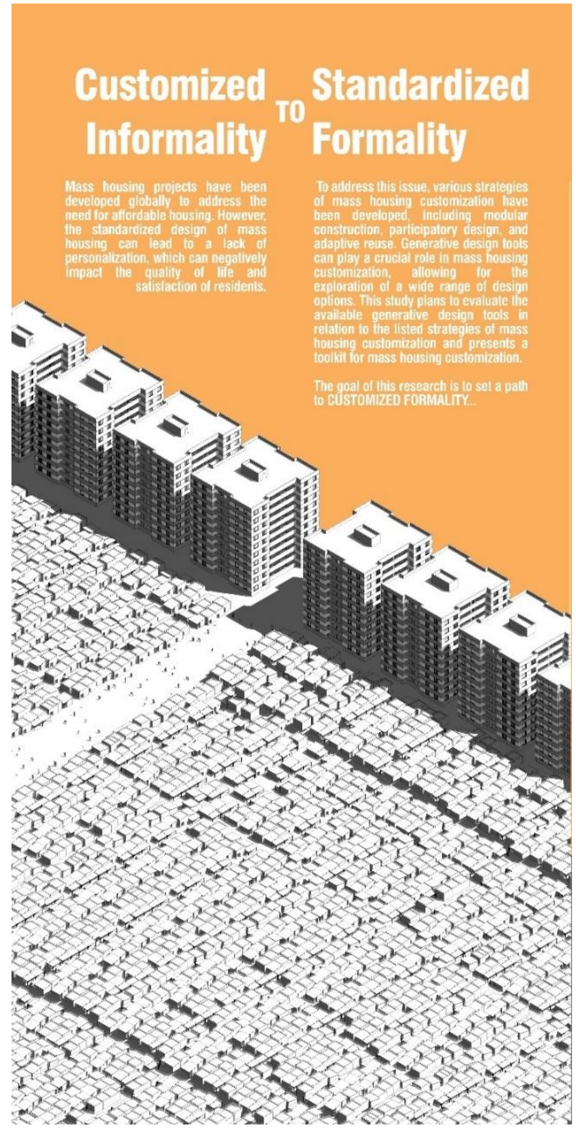
This exhibition, *Mass Housing Customization: Egypt's Challenge*, was conceived as part of a broader narrative orchestrated by the Department of Explorative Architecture at the Budapest University of Technology and Economics (BME). Under the collective vision *OUR TAKE ON AFRIKA*, multiple academic and design projects converged to explore how innovative architectural solutions could address pressing socio-spatial issues in rapidly urbanizing contexts across different regions.

This chapter details the doctoral research exhibition positioned alongside other Department of Explorative Architecture exhibits, reinforced the dissertation's argument that balancing standardization with user-driven customization can yield more sustainable and equitable mass housing solutions.

10.1.Customized Informality to Standardized Formality

This panel captures the core dilemma that the thesis addresses: the transition from informal, self-built housing—where residents often adapt spaces to individual needs—to the structured uniformity of high-rise mass-housing blocks. By contrasting “Customized Informality” with “Standardized Formality,” it underscores the study’s principal aim of bridging these two extremes through the concept of “customized formality.” The visual association highlights the thesis’s focus on reconciling the affordability and efficiency of large-scale construction with the personalized qualities typically seen in informal developments, reflecting the primary design challenge at the heart of mass housing customization research.

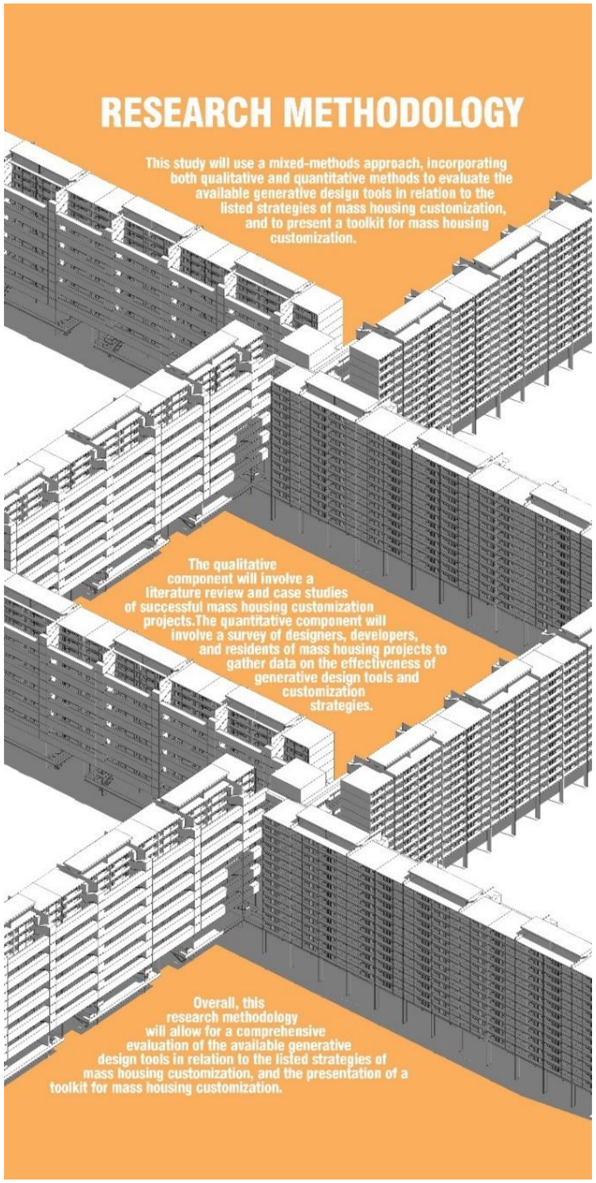
Artistically, the panel’s lower portion depicts a sprawling, organic arrangement of single-story dwellings in stark repetition, indicative of informal settlements where customization arises from grassroots necessity. Above, a cluster of tall housing blocks, rendered with clean lines and systematic order, signifies the uniformity of conventional mass-housing. The diagonal shift from informal units to formal towers visually amplifies the tension between occupant freedom and efficiency-focused standardization.



10.2.Research Methodology

This second panel focuses on the thesis's **research methodology**, visually highlighting the mixed methods approach central to investigating mass housing customization. The text emphasizes a combination of qualitative and quantitative components, namely a literature review, case studies, and a survey of industry professionals and residents. By specifying how generative design tools will be scrutinized within this framework, the panel clarifies the rigors of the investigative process and underscores the study's intention to develop and evaluate a methodical toolkit for mass housing.

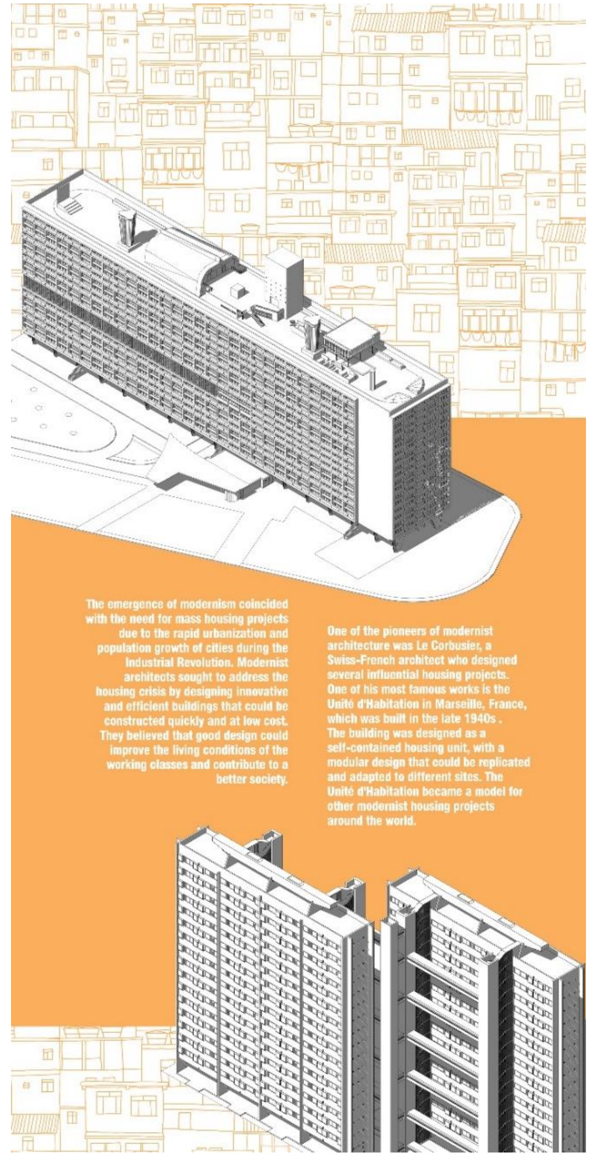
Graphically, the panel presents an array of repetitive housing blocks arranged in an isometric perspective, symbolizing the systematic nature of mass housing developments. The bold orange rectangle set against the gray scale of towering buildings delivers both the foundation and focus of the methodology: a grounded but expansive set of strategies for analysis. The recurring geometry of identical towers suggests the conventional baseline of mass housing—orderly yet repetitive—while the highlighted text segments stand out as interventions or "windows" into the investigative process.



10.3.Mass housing emergence

This panel situates mass housing development within a historical context, illustrating how modernist ideals—epitomized by Le Corbusier’s Unité d’Habitation—shaped the drive for affordable, large-scale construction. It highlights the belief in standardized, replicable units as a means of quickly addressing the housing crisis. By referencing modernism’s optimism about improving living conditions through design, the panel connects directly with current research into generative design: both seek efficiency and better-quality housing outcomes, though modernists typically relied on universal solutions, whereas the thesis underscores customization and resident involvement. The comparison underscores how today’s computational approaches can refine rather than replace the foundational lessons of early mass-housing pioneers.

Visually, the panel contrasts a towering modernist block, rendered in crisp linework and systematic layering, against a background of sketch-like, irregular facades. This contrast highlights the tension between the austere geometry of modernist high-rises—symbolizing order and industrial efficiency—and the more organic forms of everyday urban neighborhoods.



10.4.Success Cases

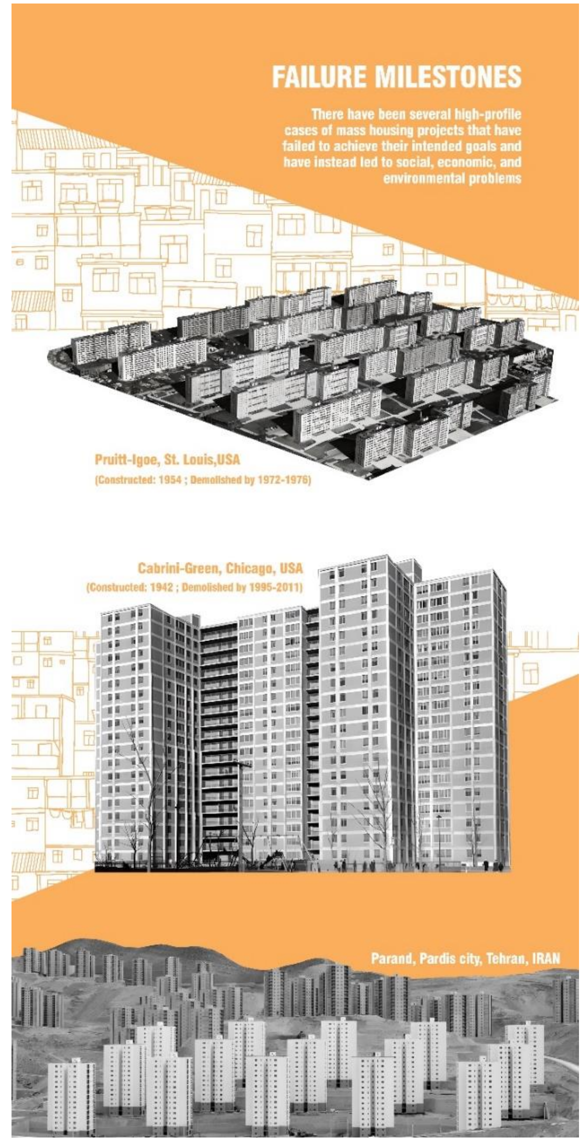
This panel highlights *success cases* in global mass housing—such as Singapore's Housing Development Board or Austria's Social Housing Program—offering practical precedents for how large-scale residential projects can achieve both affordability and quality. These examples align with the dissertation's focus on best-practice models that effectively address diverse user needs through varying degrees of customization, subsidization, and public-private collaboration.

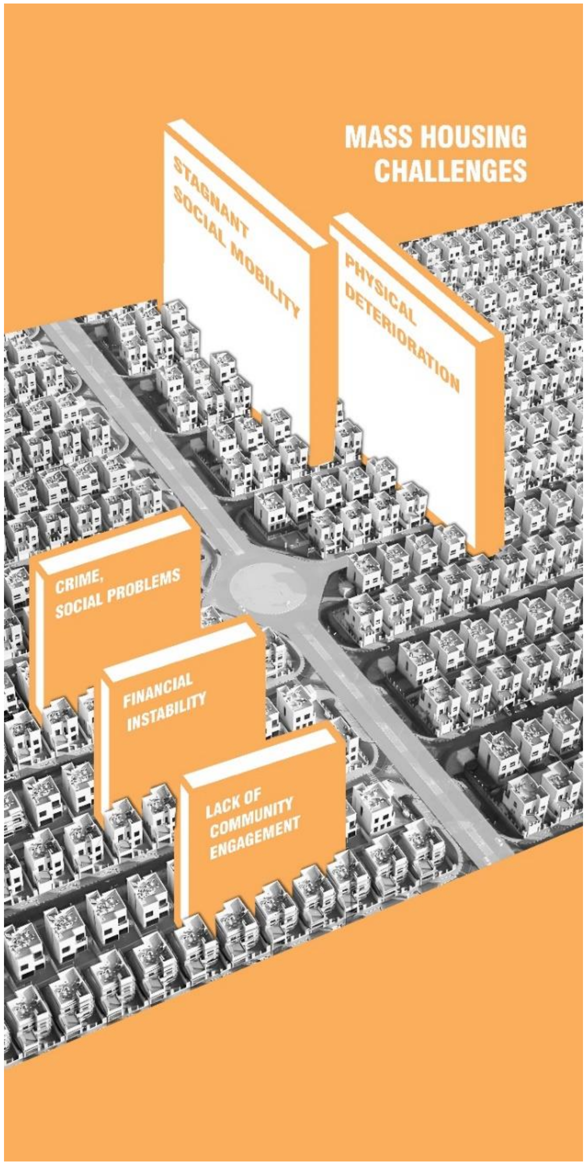
Visually, the panel uses a seamless background of extruded building outlines, arranged in a rhythmic isometric grid. This multitude of simplified towers acts as a symbolic "canvas" of standard mass housing. Cutting through this uniformity, the central orange band lists examples of successful projects, while the lower photograph showcases contemporary high-rise developments set in a real context of greenery and communal amenities. This dual-layer composition indicates a shift from mere "boxes" or line drawings to tangible, thriving neighborhoods. The clean geometry emphasizes scalability and organization, whereas the photograph suggests that customization, policy, and design can result in mass housing that is more than just repetitive units where architectural strategies can promote vibrant, livable environments.

10.5. Failure milestones

This panel underlines the consequences of poorly planned mass housing by showcasing notable failures such as Pruitt-Igoe, Cabrini-Green, and Parand in Tehran. Each serves as a reminder that large-scale residential projects, if not responsive to social dynamics, economic factors, and the changing needs of residents, can devolve into environments marked by abandonment, crime, or insufficient community infrastructure. For research centered on customization and generative design, these examples offer cautionary tales: while mass housing can address immediate quantity demands, ignoring occupant engagement, adaptability, and cultural context risks replicating the same systemic pitfalls. A key takeaway is the need for iterative design and feedback mechanisms—precisely the strengths of the generative approach highlighted in the dissertation.

Visually, the montage depicts stark, uniform high-rise blocks receding into the distance, hinting at an endless sprawl where individuality and livability might be lost. The backdrop of stylized line drawings—evoking informal or traditional urban environments—contrasts with the large, monolithic structures in grayscale. The diagonal band of orange unifies these disparate images while drawing attention to the text identifying each failed housing project.





10.6.Mass housing challenges

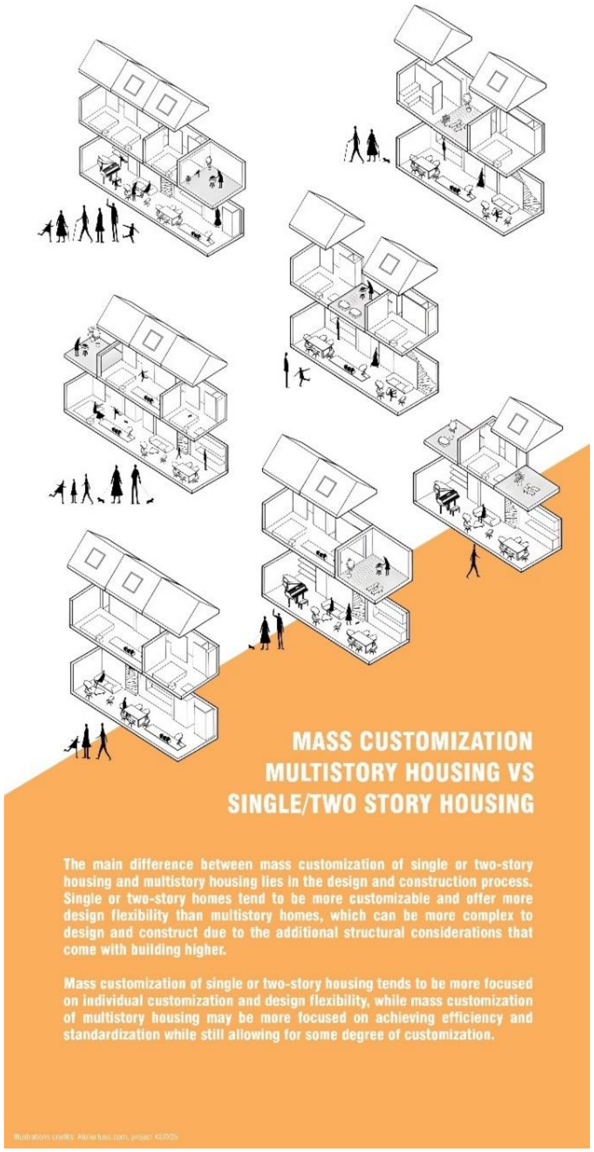
This panel spotlights overarching challenges common in mass housing developments, from stagnant social mobility and physical deterioration to crime, financial instability, and weak community engagement. These issues align with the study's argument that standardization alone cannot address the complex socio-economic factors affecting large-scale residential environments. By acknowledging how poorly designed mass housing often cultivates disconnected neighborhoods and unsustainable lifestyles, the panel underscores why the research prioritizes customizable, resident-driven approaches that go beyond mere structural efficiency.

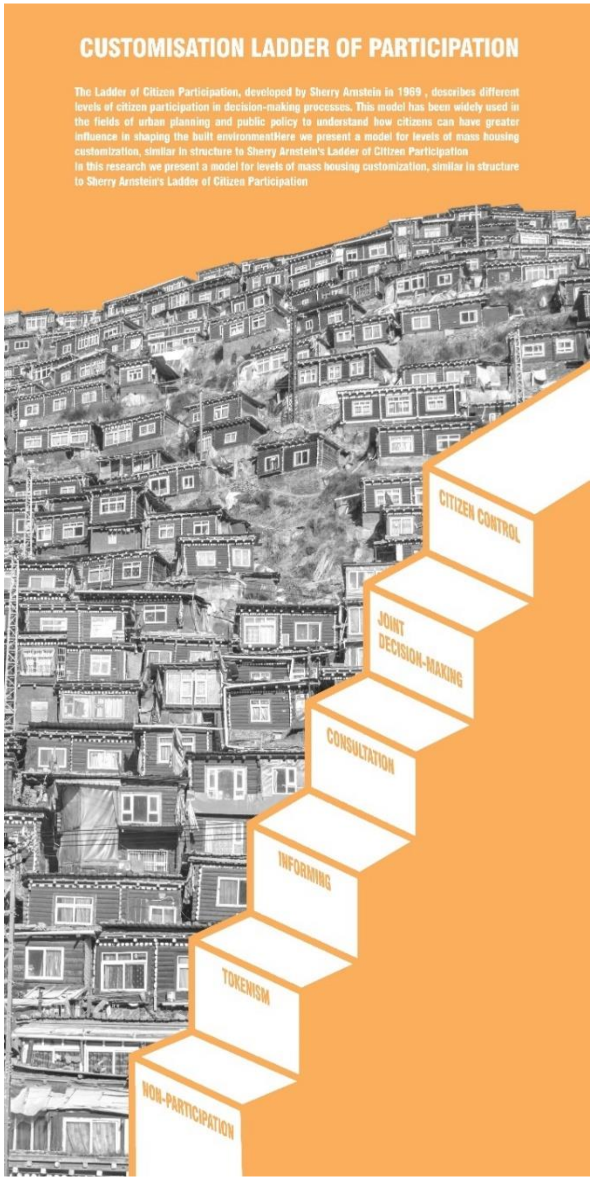
The panel features an expansive aerial view of uniform, box-like housing units, arranged in a neat but impersonal grid. Above this orderly background, oversized orange "blocks" label core social and economic challenges, as if they were looming obstacles rising out of a homogenous neighborhood. This visual metaphor highlights how these problems often overshadow the promise of straightforward mass-produced designs.

10.7.Customization needs

This panel highlights the contrast between single/two-story and multistory housing when it comes to mass customization. By emphasizing that lower-rise dwellings can offer greater individual flexibility, while taller blocks face stricter structural and regulatory constraints, it underscores a central point in the study: the balance between efficiency and personalization varies significantly based on building typology. This observation informs how a generative design toolkit might allocate different levels of customization (e.g., facade modifications, interior reconfigurations) depending on project scale, structure, and community needs.

Depicted through cutaway isometric sections, each unit reveals various living arrangements, kitchens, living rooms, and bedrooms stacked or arranged differently. providing a glimpse of how adaptable layouts can accommodate diverse family structures. The minimal line art, devoid of heavy detail, directs attention to the spatial variety within the same volumetric constraints. Meanwhile, silhouetted human figures and pets add warmth, suggesting everyday life scenes rather than abstract diagrams. The clean composition, combined with a bold orange wedge across the bottom, visually separates single/two-story designs from the more restrictive environment of high-rise buildings. This interplay of modular layouts and everyday human activities echoes the thesis's stance that customization goes beyond superficial choices, extending into how people truly live and adapt their homes over time, even in the context of large-scale housing developments.





10.8. Customization level of participation

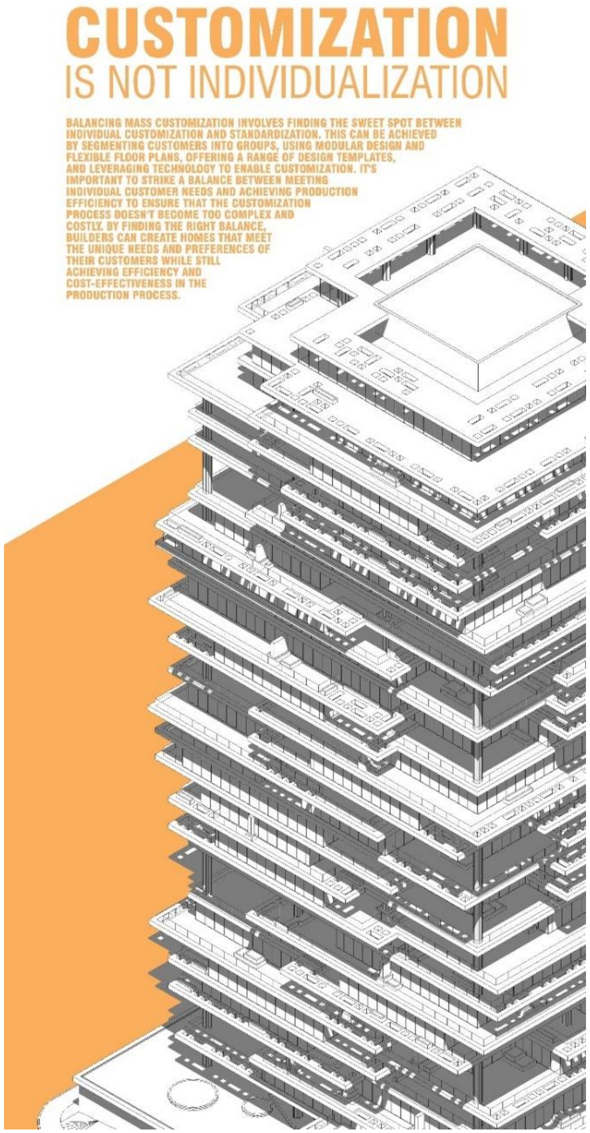
This panel directly connects Sherry Arnstein's "Ladder of Citizen Participation" to mass housing customization, underscoring how differing levels of resident involvement can substantially alter project outcomes. By showing stages from "Non-Participation" to "Citizen Control," it highlights the thesis's stance that genuine customization requires more than token consultation, it demands shifting greater decision-making power to occupants. This aligns with the research focus on user-driven customization strategies, where generative design tools can facilitate real-time feedback loops, encouraging collaborative approaches rather than top-down prescriptions.

The backdrop of densely layered, hillside dwellings contrasts with the crisp, ascending blocks of Arnstein's ladder. The organic complexity of stacked homes symbolizes naturally evolved neighborhoods where residents determine their own spatial adaptations. In front, the simple geometric "steps" illustrate a clear progression toward deeper occupant influence. The stark, tiered composition emphasize how climbing each "step" provides increasing agency, reflecting the thesis's theme that truly customized mass housing relies on a participatory structure in which the occupants are not merely informed but actively co-deciding the final design.

10.9. Standardization is Limitation

This panel challenges the notion that standardization and customization must be at odds. While mass housing often relies on standardized design elements for efficiency and cost-effectiveness, the thesis argues that thoughtful, flexible frameworks can still enable occupant-specific adaptations. Thus, this message aligns with the central premise that "standardization is not limitation"—that it is possible to achieve both operational benefits at scale and meaningful resident customization when leveraging informed design decisions, potentially assisted by AI-driven or generative methods.

The panel focuses on a single high-rise block rendered in monochromatic line art. Its repetitive balconies and vertically stacked floor plans embody the essence of standardized high-rise construction. By rising sharply against a bold orange background, the building suggests a sense of firm uniformity. Even though the structure appears formulaic, the composition and message emphasize that rigorous standardization need not stifle design creativity or user choice. Instead, the simplified, modular nature of these balconies, floors, and facade elements can be curated to accommodate varied preferences—tying directly into the study's advocacy for a balance between mass production and occupant-specific customization.



10.10.Customization is not individualization

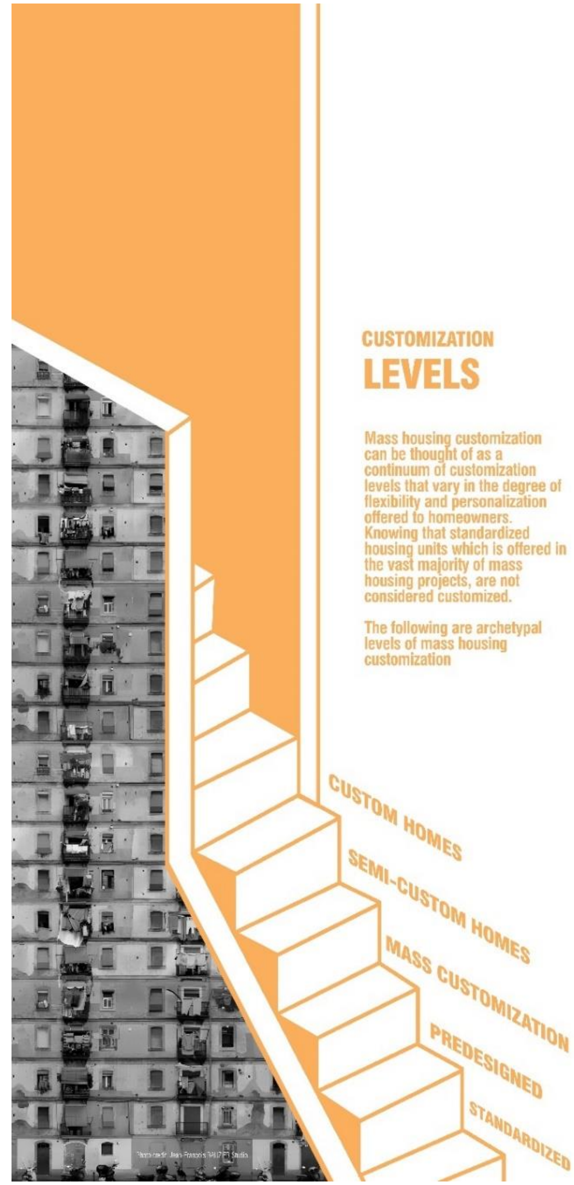
This panel articulates the difference between mass customization and complete “individualization.” It reinforces the thesis’s argument that generating a broad spectrum of design options, tailored to different resident groups, can still achieve production efficiency if approached systematically. Rather than customizing each unit to an extreme, the goal is to segment occupant needs into manageable “option sets,” applying strategies such as modular design and flexible floor plans. This framework matches the thesis’s advocacy for generative tools, which enable iterative exploration of design variations without devolving into one-off, fully unique units that compromise cost and building timelines.

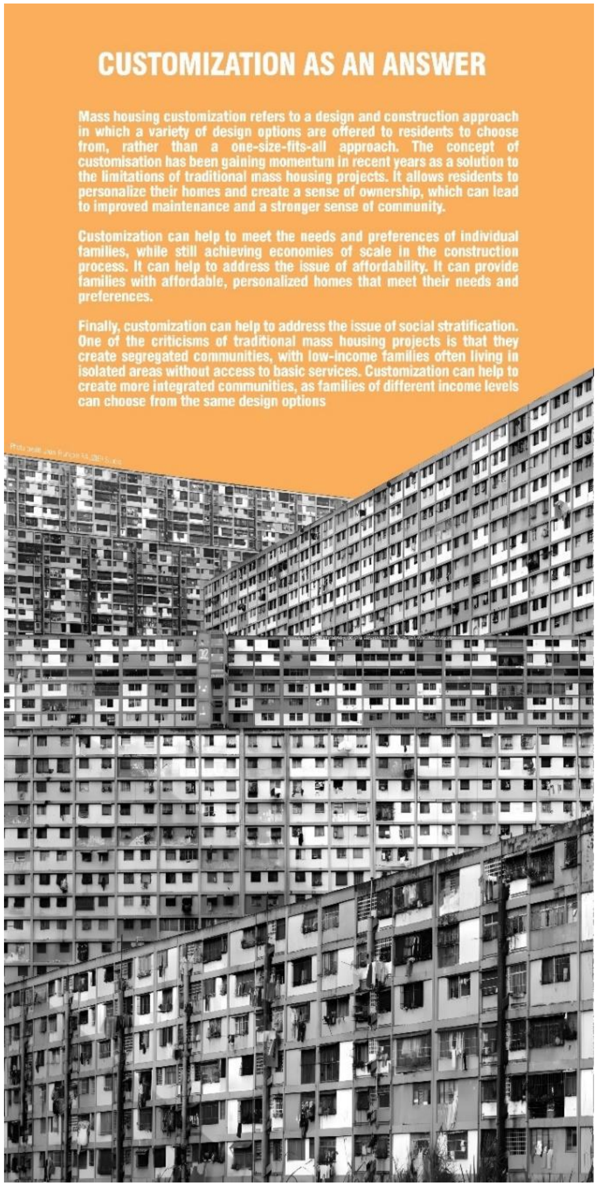
The stacked floorplates capture the essence of a layered approach to housing design, hinting at how multiple customization tiers might be integrated within a single structure. Each “slice” suggests possible variations in layout or function, collectively forming a coherent, vertically integrated building. It mirrors the stacked concept by emphasizing that customization need not imply an overabundance of unique solutions. The line-art style keeps the focus on the building’s structure and internal subdivisions, reinforcing the idea that modular, generative thinking allows for variations while preserving an overall framework conducive to efficient mass production.

10.11. Levels of customization

This panel introduces a continuum of customization levels, from fully standardized to fully custom, and situates "mass customization" as a midpoint on that spectrum. By illustrating how most mass housing traditionally remains at the "standardized" end, it echoes the thesis's premise that residents seldom have meaningful input on layout or finishes. The gradation also reflects the study's interest in flexible frameworks, where generative design tools can offer multiple options without compromising affordability or efficiency. It supports the idea that mass housing doesn't have to be either fully standardized or entirely custom-built; instead, it can offer strategic levels of personalization.

The panel uses an ascending "staircase" graphic to depict different customization tiers—"Standardized," "Predesigned," "Mass Customization," "Semi-Custom," and "Custom Homes." This clear, stepped structure evokes a hierarchy of choices, with each riser symbolizing a new level of design input for occupants. Meanwhile, the adjacent grayscale photograph of aging building facades delivers a sense of everyday reality where balconies or exterior walls have been informally modified, hinting at occupants' desire for personal adaptation. The tension between this organic, improvised modification and the crisp, schematic steps visually captures the research goal: to formalize and streamline such customization via well-organized frameworks and generative design methods.





10.12. Customization as an answer

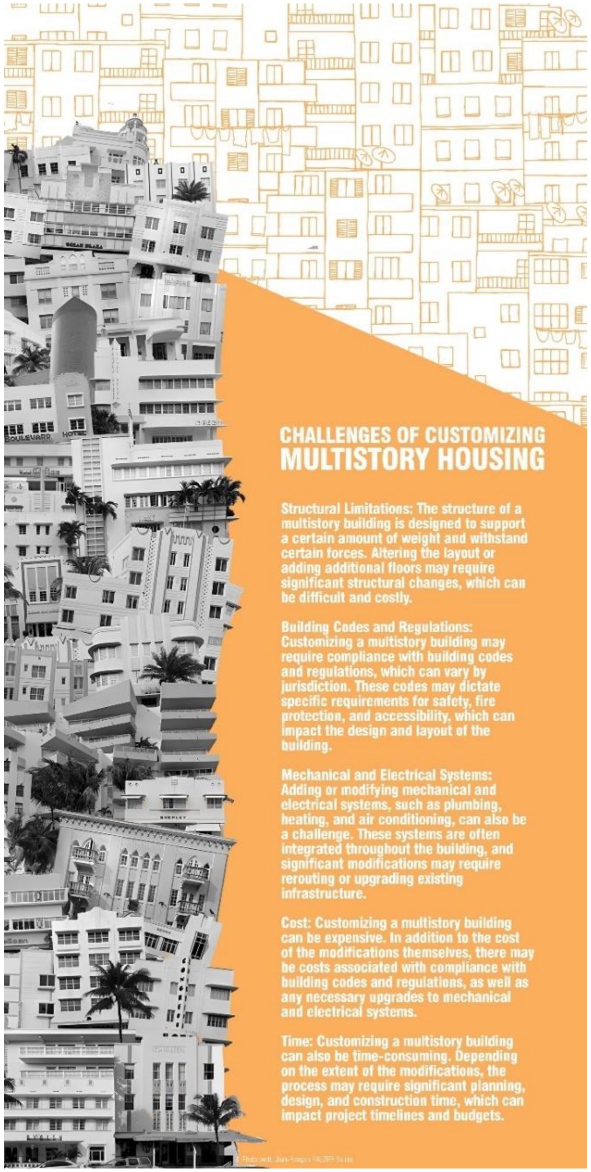
This panel frames mass housing customization as a direct response to the shortcomings of monolithic, standardized developments. By allowing residents to select from various design options, housing projects can promote stronger community identity and occupant satisfaction—two central themes in the thesis. It addresses how customization can meet diverse family needs without sacrificing the economies of scale critical to large-scale construction. Moreover, the text explicitly links customization to social integration, indicating that if all income levels can access the same range of design choices, it helps avert the physical and social segregation commonly associated with traditional mass housing.

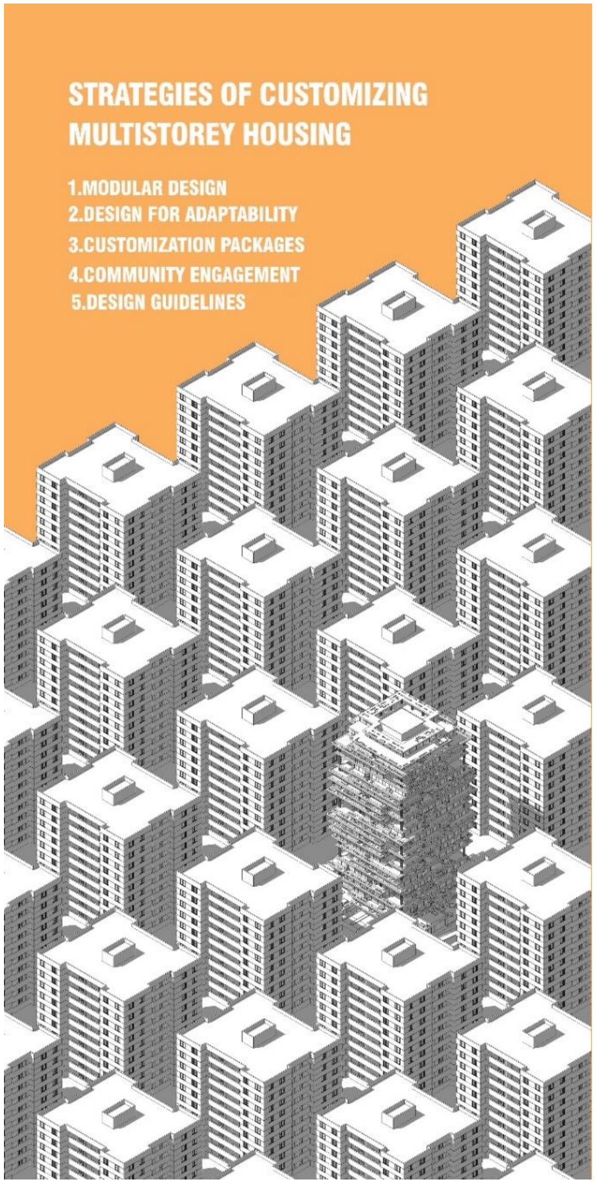
The panel's layered collage of high-rise apartments in grayscale underscores the repetitive, impersonal aesthetic frequently criticized in mass housing. This stark uniformity is contrasted with the vibrant orange header and accompanying text, which presents "Customization as an Answer"—an invitation to reimagine how these repetitive blocks might be diversified through personalized modules, finishes, or layouts. The predominantly black-and-white backdrop spotlights the unrelenting sameness of many mass housing projects, while the orange band suggests a new horizon of possibilities, capturing the essence of the research: that strategic customization can reconcile large-scale efficiency with occupant agency and social cohesion.

10.13. Limitations of customization

This panel focuses on the practical obstacles that come with adapting multi-story buildings for customization, touching on structural, regulatory, mechanical, and financial factors. Such constraints are central to the thesis's exploration of how generative design might enable greater flexibility without compromising safety, code compliance, or cost-effectiveness. By enumerating these specific challenges, the panel underlines why the research advocates strategies like modular components or parametric modeling, which can dynamically adapt designs within these real-world constraints. In other words, while the thesis champions heightened occupant input and variable interior configurations, it also acknowledges that larger vertical structures necessitate advanced planning, specialized calculations, and software support, hence the pivotal role of computationally driven approaches.

The collage of diverse building facades stacked in a playful, gravity-defying arrangement, expresses the complexity and sheer diversity of design elements in a multistory context. It visually captures the idea that, unlike lower-rise housing where a single module might suffice, taller structures accumulate layers of design decisions: each additional story amplifies structural, mechanical, and regulatory intricacies. The background's minimal line drawings of windows and balconies provide a gentler contrast, allowing the crowded vertical "tower of facades" to stand out as a vivid emblem of myriad customization aspirations.





10.14. Strategies of customization

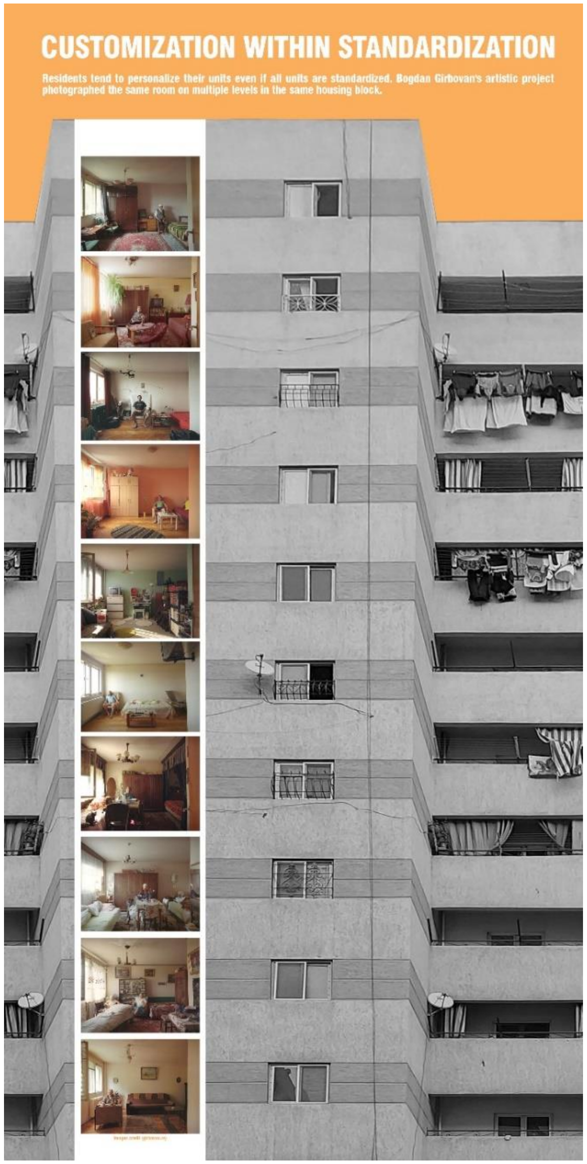
This panel enumerates five key strategies—Modular Design, Design for Adaptability, Customization Packages, Community Engagement, and Design Guidelines—that the study identifies as pivotal for customizing multistory housing. Each approach aligns with the research goal of striking a balance between the benefits of standardized mass production and the needs of individual occupants. By outlining these strategies, the panel provides a practical roadmap for how generative design tools, participatory processes, and flexible construction methods can converge to create more resident-focused high-rise developments.

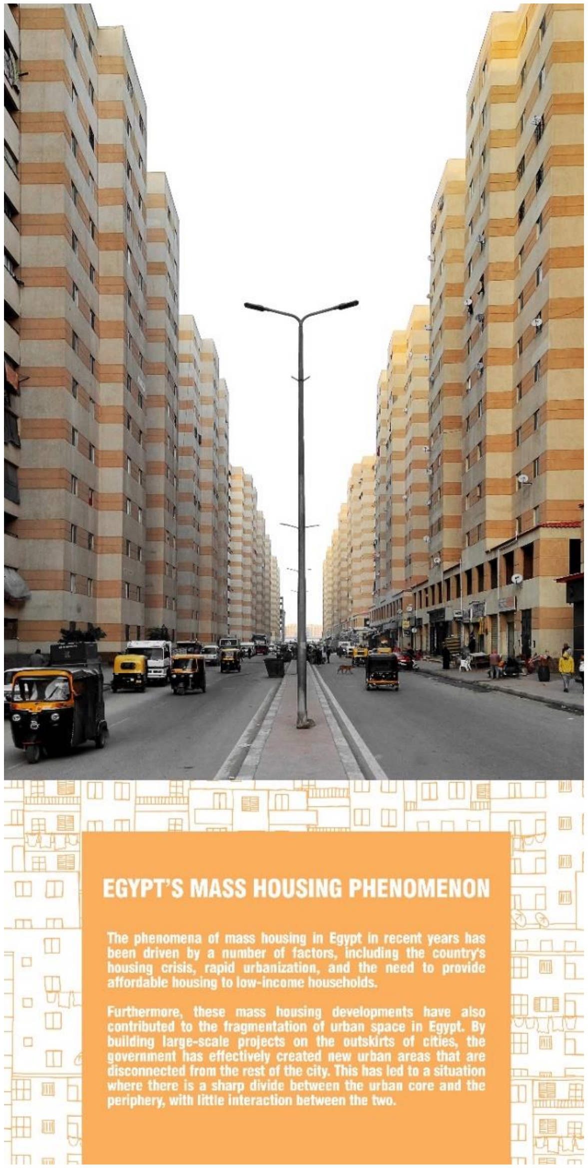
A field of nearly identical tower blocks forms the background in a regimented grid, metaphorically representing the default "sea" of uniformity common in mass housing. In contrast, one building at the lower right corner appears intentionally altered, its floors visually sliced or expanded, illustrating the core concept of customization. This subtle yet striking difference draws the eye and demonstrates how targeted modifications (such as added balconies, modular facade elements, or reconfigured floor layouts) can differentiate a single tower in a mass of lookalikes. The orange header lists the core strategies, while the predominantly gray palette in the towers emphasizes both the potential homogeneity of typical high-rise developments and the capacity for selective, strategic intervention.

10.15. Customization within standardization

This panel illustrates how residents naturally introduce personalization within otherwise standardized units. By featuring photographs of the same type of room repeated across multiple floors, it demonstrates the varied interior style, furniture arrangements, and spatial modifications residents use, even in buildings that offer no formal customization options. This organic adaptation underscores the study's central argument: occupants have an inherent desire to tailor their living environments, and generative design approaches can channel that impulse into more structured, yet flexible, housing solutions.

On the left, a vertical column of interior shots provides an intimate glimpse of individual lifestyles, plants, personal objects, color palettes, set against an austere, repetitive facade. The stark facade symbolizes the rigidity of mass production, while the diverse living spaces highlight how personal creativity flourishes regardless. The composition invites viewers to compare each interior photo, revealing the distinct personality of each household despite uniform apartment layouts. It amplifies the research theme that customization need not be all-or-nothing; even minimal modifications can greatly enhance residents' sense of ownership, prompting architects and planners to consider how design frameworks, particularly those informed by generative methods, might facilitate deeper and more efficient personalization.





10.16. Egypt's mass housing phenomenon

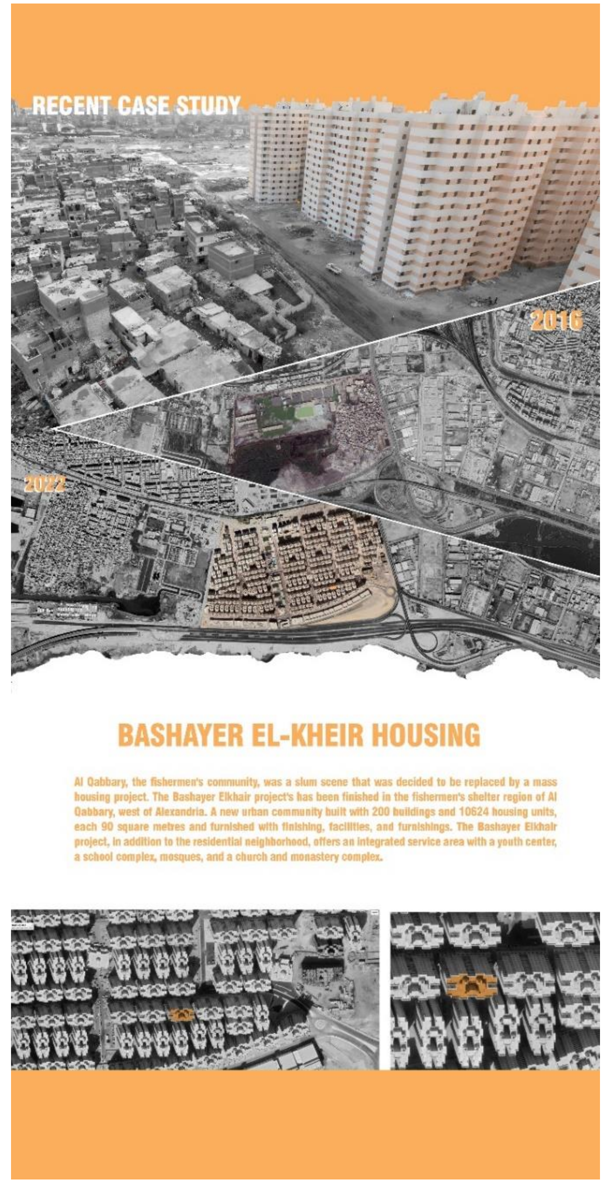
This panel provides context specific to Egypt's mass housing phenomenon, highlighting the factors, rapid urbanization, a national housing crisis, and budgetary constraints, that have prompted large-scale developments on city outskirts. By doing so, it underpins the study's focus on customization in regions where top-down projects frequently result in housing blocks disconnected from established urban fabric. The text underscores the tension between providing sheer quantity of units and the lack of integration with local contexts. This observation sets the stage for the research goal: to explore how generative design approaches could deliver affordable housing that remains socially and spatially connected, rather than merely sprawling.

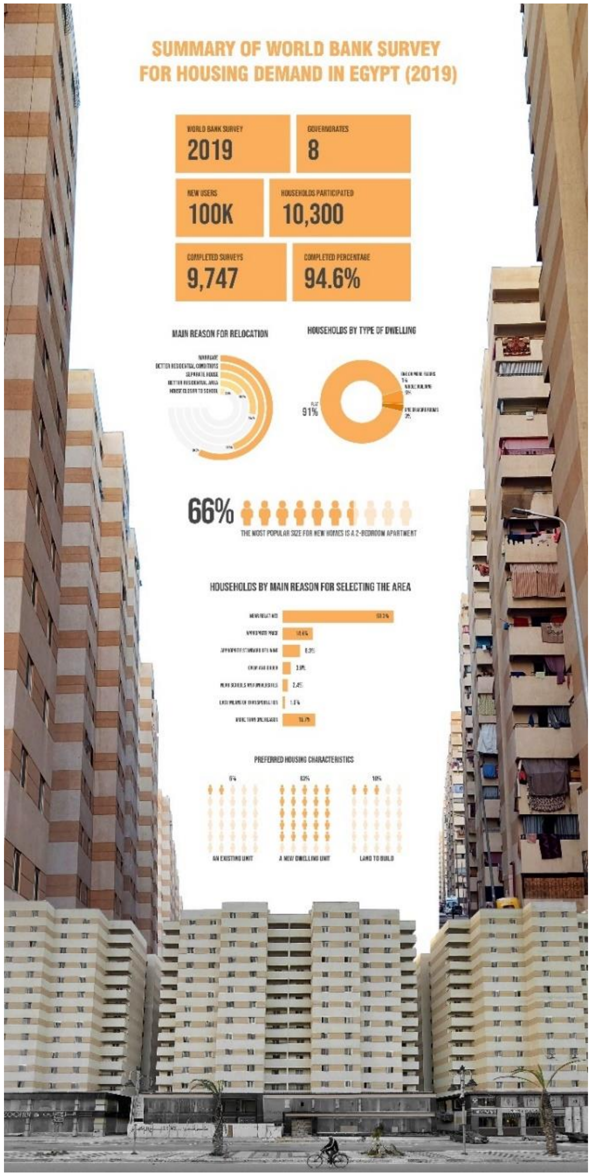
The photograph of parallel high-rise blocks receding into the distance emphasizes the monolithic scale of these developments, while the lively scene of cars, and pedestrians suggests real, everyday life unfolding despite the building uniformity. The composition visually suggests a sense of being "edged in" by identical towers, foreshadowing the social isolation and fragmentation mentioned in the text. Overall, the panel illustrates the scale and socio-spatial implications of mass housing in Egypt—critical factors in shaping the study's pursuit of more responsive, user-involved design solutions.

10.17. Bashayer El-Kheir housing

This panel presents a recent case study: the Bashayer El-Kheir housing initiative, built to replace informal settlements in Alexandria. It directly informs the thesis by exemplifying the Egyptian government's approach to large-scale redevelopment demolishing so-called slum areas and erecting uniform residential blocks. In doing so, it crystallizes many of the research's focal points: the challenge of transitioning from informality to standardization, the question of how much user involvement shapes new neighborhoods, and whether such projects can incorporate customization features to enhance resident satisfaction. The inclusion of integrated facilities (youth centers, mosques, schools) spotlights a broader, holistic approach that ties into the study's vision for more complete, community-oriented mass housing.

The panel contrasts older, low-rise dwellings and new high-rise towers in a split scene, emphasizing the dramatic shift in scale and form. A series of aerial images from different years highlight rapid transformation, showing how an organic, densely packed settlement has been replaced with arrayed multi-story blocks. The perspective transitions from top-down satellite shots to an angled photograph on-site, visually uniting macro-scale urban planning with the human-scale reality of replaced neighborhoods.





10.18. Egypt's housing demand

This panel compiles World Bank survey data on housing demand in Egypt, presenting statistics such as household relocation motives, preferred unit types, and reasons for selecting specific areas. By quantifying how many families value proximity to relatives, pricing, or a certain standard of living, it strengthens the thesis argument that consumer preferences in mass housing are more appropriate than a one-size-fits-all model implies. These quantitative insights validate the need for flexible design options, an essential component of the dissertation's generative design strategy.

Framing the data, large-scale apartment buildings flank either side, symbolizing the current reality of mass housing in Egypt, towering facades where uniformity often reigns. This composition simultaneously emphasizes the *macro-level*, data-driven perspective on Egyptian housing needs and the *micro-level* physical form of high-density blocks. The partial transparency in some of the buildings, or cutaways, references potential "layers" of information: while standard exteriors remain constant, the residents within hold varied preferences that the study proposes accommodating through intelligent, user-oriented design methodologies.

Summary

The sequence of panels collectively constructs a coherent storyline that takes visitors from the broad historical and conceptual context of mass housing to specific strategies and case studies for customization. At the outset, the panels contrasts the organic variety of informal settlements against the uniformity of standardized blocks, establishing the central tension: how to balance large-scale efficiency with user-tailored design. The following sections then explore modernism's role in shaping an early vision of mass housing, contrast globally recognized successes and failures, and identify common pitfalls such as social segregation, stagnant mobility, and weak community engagement.

Moving deeper into the content, the exhibition focuses on methodological considerations. One panel explains the mixed-methods research design, including qualitative and quantitative components aimed at developing a generative design toolkit. Another introduces Sherry Arnstein's Ladder of Participation, underscoring the importance of resident involvement. The narrative continues by examining standardization and customization side by side, showing that carefully structured approaches—rather than complete uniformity or total individualization—offer a middle ground beneficial to both developers and occupants.

Subsequent panels highlight case-specific dimensions. They address Egypt's mass housing phenomenon and discuss the Bashayer El-Kheir project, which replaced

informal settlements with new high-rise complexes. Comparative data, such as the World Bank survey on Egyptian housing needs, illustrates the variability of household preferences. By emphasizing the mismatch between top-down developments and localized resident demands, these panels reinforce why generative design and participatory frameworks can fill the gap.

Finally, the exhibition culminates with strategic proposals for customizing multi-story housing, listing modular design, design for adaptability, community engagement, and clear design guidelines as pivotal factors. Visual examples of personalized interiors in otherwise uniform blocks show how residents are already making informal modifications, hinting that thoughtful design—and especially AI- or algorithm-assisted methods—could systematically integrate this adaptive impulse.

In sum, the wall arrangement weaves together historical context, theoretical debates, lived experiences, and design methodologies into one continuous narrative. It argues that customization in mass housing is both necessary and achievable, provided architects, planners, and policymakers adopt more flexible, resident-centric approaches precisely the core of the research underlying this exhibition.

"MORE TAKE ON AFRICA" Exhibition

the Department of Explorative Architecture of the BME Faculty of Architecture's exhibition in the FUGA Budapest Center of Architecture.

Following the introduction of the Department of Explorative Architecture of the BME Faculty of Architecture four projects at the TimeSpaceExistence exhibition 2023, held in Venice, with the motto OUR TAKE ON AFRICA. The exhibition in the FUGA Budapest Center of Architecture (21 February 2024 – 10 March 2024) was complemented with further plans, mock-ups, and photos which were only virtually present in Venice due to the physical limits of the installation – this is how the MORE TAKE ON AFRICA exhibition came into existence.

11.Masterwork: Tabbab Municipality Building

Project Owner: Assir Municipality, KSA

Project Team:

Tabbab Engineering department:

Project Manager and Technical Supervisor: Mr. Saeed Al Ghawaa

Urban Planner: Mr. Khalid AlEmary

Architectural Designers: Mr. Ahmed Mokhtar, Mr. Mohamed Raslan

Civil Engineer: Mr. Mostafa Awis

MEP Engineer: Mr. Moataz Abo Elmagd

Inaugurated: 2022

Total built-up area: 920 m^2

As architects, every project brings its own set of challenges and rewards, but designing a contemporary structure in Tabbab, a municipality with a rich cultural heritage and historical significance, presented us with an extraordinary opportunity to create something truly unique.

The Unique Heritage of Tabbab

Tabbabs is a sub-municipality in the Asir region, located 25 km northwest of the city of Abha in the Kingdom of Saudi Arabia. It holds immense historical significance as it was built during the era of the first Saudi state. Tabbab served as the first political, cultural, and economic capital of the Asir region during the rule of the first Saudi state. The area is renowned for its important historical and heritage sites, most notably the Tabb Mosque, founded in 1221 AH by Prince Abdul Wahhab bin Amer Abu Nuqta Al Mutahami during the reign of Imam Saud bin Abdul Aziz. The village also features the palaces of the princes of the Abu Nuqta Al Mathami family, showcasing the rich architectural legacy of the region.

Situated in a mountainous agricultural area at an altitude of 2,250 meters above sea level, Tabbabs is characterized by its moderate climate in summer and a cool, crisp winter, often accompanied by heavy summer rains. This unique topography and climate further enhance the area's distinctive character and cultural richness.

Blending Tradition with Modernity

The design brief required a building that would honor the historical essence of Tabbab while offering a modern interpretation of its traditional architectural motifs. Tabbab' rich architectural heritage, characterized by intricate patterns, earthy tones, and communal spaces, served as our inspiration. The goal was to craft a structure that echoed these traditional elements while seamlessly incorporating modern functionality and aesthetics.

Our client shared a profound attachment to the cultural roots of the region and sought a design that would act as a bridge between the old and the new. This meant maintaining a deep sensitivity to the site's history and heritage while creating a forward-thinking, sustainable design that aligned with contemporary lifestyles and business needs.

Overcoming the Challenges of a Remote Site

The site itself posed its own unique set of challenges. Located in a remote area, access to resources, skilled labor, and materials was limited. This meant meticulous planning and coordination were vital from the very beginning. We sourced local materials wherever possible, not only to pay homage to the area's natural beauty but also to reduce

logistical complexities and our overall environmental footprint.

Additionally, the site's topography required thoughtful integration. Preserving the natural landscape was a priority, which demanded innovative design solutions to ensure minimal disruption while maximizing the aesthetic harmony between the building and its surroundings.

Respecting Cultural Heritage

A key challenge was understanding and honoring the cultural distinctions of Tabbab. The architectural language of the municipality has evolved over centuries, shaped by its climate, traditions, and way of life. We spent significant time researching and consulting with local historians, artisans, and residents to ensure our design resonated authentically with the community's identity.

This cultural dialogue heavily influenced our choice of materials, spatial arrangements, and façade treatments. For example, traditional geometric patterns and perforated screens were reimagined in a modern context to allow natural light to filter through the interiors while maintaining privacy, an essential aspect of traditional Tabbab architecture.

Balancing Unique Client Requirements

The client's vision required us to walk a fine line between respecting tradition and meeting modern needs. This was particularly evident in the functional requirements of the building, which included open, flexible office spaces, state-of-the-art technology, and sustainable design practices.

To address this, we incorporated innovative features such as energy-efficient cooling systems that respect the hot climate of the region, while ensuring the design seamlessly integrated with the traditional aesthetic. Communal spaces were designed with a nod to the traditional courtyards of Tabbab, promoting a sense of community and connection, while still serving as practical, functional areas for modern usage.

The Final Result

The completed project stands as a testament to the collaborative effort of our team, our client, and the local community. It merges the charm and identity of Tabbab' heritage with the elegance and functionality of modern design. The structure not only respects the past but also looks toward the future, setting a benchmark for how architecture can celebrate local culture in a contemporary world. This project has been a profound learning experience for our team. It reminded us that architecture is not just about building structures; it's about storytelling, honoring history, and shaping the future in harmony with the environment and the people it serves.

12. Appendices

Appendix 1:Toolkit Detailed Presentation

1.Stakeholder Involvement

In the dynamic landscape of mass housing customization, understanding and integrating the diverse needs and preferences of future residents are vital. Traditional methods like surveys and focus groups, while effective, can be resource-intensive and time-consuming, especially when dealing with thousands of potential residents. Here, the adoption of Natural Language Processing (NLP) AI tools emerges as a revolutionary approach to efficiently capture and analyze resident input, offering a scalable solution for personalizing mass housing projects.

1.1.Integration of NLP in Mass Housing Customization

NLP AI tools, such as OpenAI's GPT-3, IBM Watson Natural Language Understanding, and Google Cloud Natural Language API, provide powerful platforms for processing and understanding vast quantities of textual data generated from resident surveys, feedback forms, and focus group transcripts. By analyzing this data, NLP tools can identify key themes, preferences, and concerns expressed by residents, translating these into actionable insights for architects and urban planners.

Examples and Capabilities

- OpenAI's GPT-4 excels in generating human-like text responses, making it an ideal tool for interpreting open-ended survey responses and summarizing complex feedback into coherent themes and preferences.
- IBM Watson Natural Language Understanding offers advanced sentiment analysis and emotion detection, allowing for the understanding of resident feedback, which is crucial for addressing not just the functional but also the emotional aspects of housing design.
- Google Cloud Natural Language API provides entity recognition and classification features, enabling the identification of specific design elements and features mentioned by residents, from green spaces and play areas to privacy concerns and communal facilities.

1.2.Application in Concept and Design Development Phases

Integrating insights derived from NLP analysis into the Concept and Design Development phases ensures that mass housing projects are not only architecturally sound but also deeply aligned with the needs and aspirations of their future inhabitants. This process allows for the customization of housing units and communal spaces to reflect the clustered preferences identified.

2.Conceptual Design Phase

The Conceptual Design Phase is critical in mass housing projects, setting the foundation for innovative, sustainable, and resident-centered housing solutions. In this phase, architects and designers harness the power of generative design tools to explore a vast array of design possibilities, iteratively refining concepts based on feedback, environmental considerations, and aesthetic aspirations. Among the array of tools available, Digital Blue Foam, Giraffe Build, and Architectures stand out for their unique capabilities and contributions to the conceptual design process.

2.1.Digital Blue Foam

Digital Blue Foam excels in enabling architects to quickly generate and evaluate design alternatives. Its strength lies in:

- Digital Blue Foam utilizes AI-driven algorithms to produce a wide range of design options based on specified constraints and parameters, such as site conditions, spatial requirements, and user-defined goals, making it invaluable for early exploration.
- Seamlessly integrating with Building Information Modeling (BIM) systems, Digital Blue Foam facilitates a data-rich design process, allowing for the consideration of construction costs, materials, and sustainability metrics from the conceptual stage.

- Designed for collaboration, it allows teams to work together in real-time, sharing ideas, feedback, and iterations, ensuring a cohesive approach to the conceptual design.

A screenshot from Digital Blue Foam, a powerful tool for housing concept generations, (source:author)

2.2.Architectures

Architectures focuses on the customization aspect of housing design, offering solutions that cater to the diverse needs of future residents. It stands out for:

- Offering a library of design templates that can be customized according to specific project needs, Architectures simplifies the process of creating unique housing units that reflect varied lifestyles and preferences.

- It supports a modular approach to design, allowing for the efficient scaling and replication of units while providing opportunities for customization in layout, façade, and interior finishes.

- Architectures integrates real-time visualization features, making it easier for clients and stakeholders to understand and engage with the design concepts, facilitating a more inclusive design process.

: A screenshot from Architechtures, a web-based generative design tool, (source: auhor)

In the Conceptual Design Phase, these tools collectively offer a strong suite of capabilities that address the core challenges of mass housing projects. By leveraging Autodesk Forma's generative design prowess, Giraffe Build's spatial planning and contextual analysis, and Architectures' focus on customization and modular design, architects can lay a strong foundation for the development of mass housing projects that are innovative, sustainable, and closely aligned with the needs and aspirations of their future inhabitants.

3.Planning and Feasibility Analysis

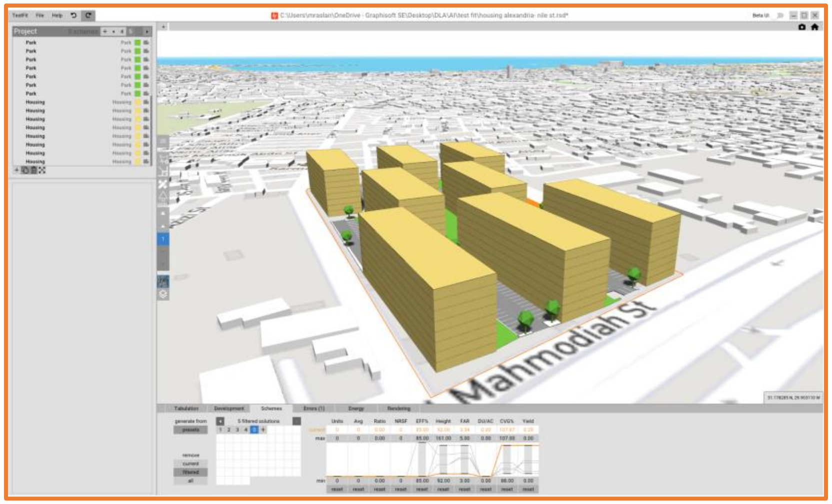
In the Planning and Feasibility Analysis Phase of mass housing projects, architects and urban planners assess the viability of their conceptual designs, focusing on practical considerations such as budget constraints, regulatory compliance, and site-specific challenges. This phase is pivotal in transitioning from innovative concepts to actionable plans, requiring tools that provide detailed insights into housing calculations, cost estimations, and regulatory adherence. TestFit and Giraffe Build emerge as exemplary tools, each offering distinct capabilities that support the intricate demands of this phase.

3.1.TestFit

TestFit is a real-time configurator that specializes in solving complex site planning and unit mix challenges, making it a powerful tool for feasibility studies and initial planning stages. It is particularly valued for:

- TestFit automates the analysis of site constraints, allowing planners to input site parameters and instantly generate optimal building configurations, maximizing land use while adhering to zoning regulations.

- Integrating cost estimation functionalities, TestFit enables architects to assess the financial feasibility of different design options early in the planning process. This feature helps in making informed decisions that align with budgetary limitations and investment objectives.
- Offering an interactive interface, TestFit allows users to manually adjust generated plans, providing flexibility in refining designs based on stakeholder feedback, without compromising the efficiency of automated configurations.
- By facilitating the visualization and sharing of design scenarios, TestFit enhances collaboration among developers, architects, and urban planners, ensuring that all parties are aligned in the project's vision and feasibility considerations.



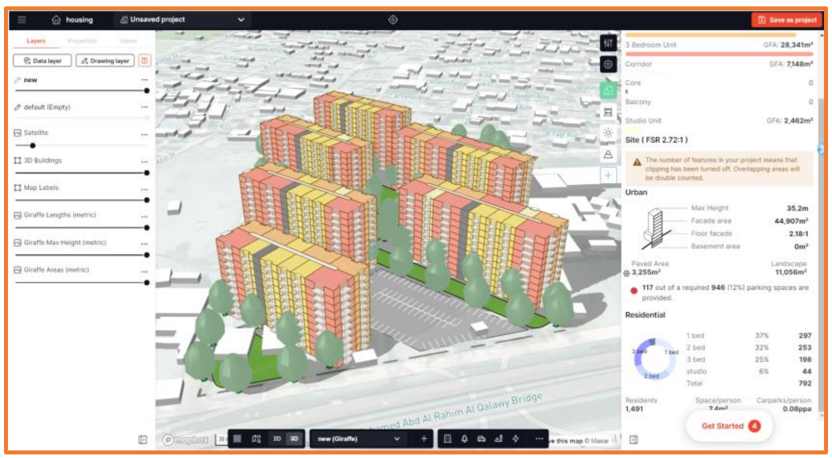
A screenshot from TestFit, showcasing comparative analysis of geenerated options at the bottom of the screen, (source:author)

3.2.Giraffe Build

Returning from the Conceptual Design Phase with its spatial planning capabilities, Giraffe Build also shines in the Planning and Feasibility Analysis Phase, attributed to:

- Beyond spatial planning, Giraffe Build offers in-depth analysis tools, spatial calculations, and cost calculations.
- It aids in ensuring that designs comply with local building codes and regulations, a critical aspect of feasibility analysis. By incorporating regulatory constraints into the design process, Giraffe Build helps avoid potential project delays and redesigns.

- Giraffe Build's cloud-based platform encourages collaboration across disciplines, allowing urban planners, environmental consultants, and community stakeholders to contribute insights, ensuring that the project is feasible from multiple perspectives.
- With its capability to integrate various data sources, including GIS data and urban datasets, Giraffe Build enables data-driven decision-making, supporting the development of projects that are both viable and contextually integrated.



A screenshot from Giraffe Build, illustrating the AI-supported spatial analysis that the tool offer, (source:author)

The Planning and Feasibility Analysis Phase is critical in translating conceptual designs into viable projects. TestFit and Giraffe Build offer complementary strengths that

address this phase's challenges. TestFit's real-time configurator and cost estimation tools are invaluable for assessing the practical aspects of site use and financial viability. In contrast, Giraffe Build's analysis capabilities ensure that projects are not only feasible but also sustainable and compliant with regulatory standards. Together, these tools equip architects and planners with the necessary resources to make informed decisions, laying the groundwork for successful mass housing projects.

4. Environmental Analysis

The Environmental Analysis Phase in mass housing projects is not just a trend but a critical necessity, addressing the growing concerns about environmental impact, resource consumption, and long-term inhabitant well-being. This phase involves evaluating designs against sustainability criteria such as energy efficiency, material sustainability, water usage, and integration with the natural environment. The importance of sustainability in mass housing comes fromthe important role these developments play in urban environments, where they can either contribute to or alleviate issues like carbon footprint, urban heat islands, and resource depletion.

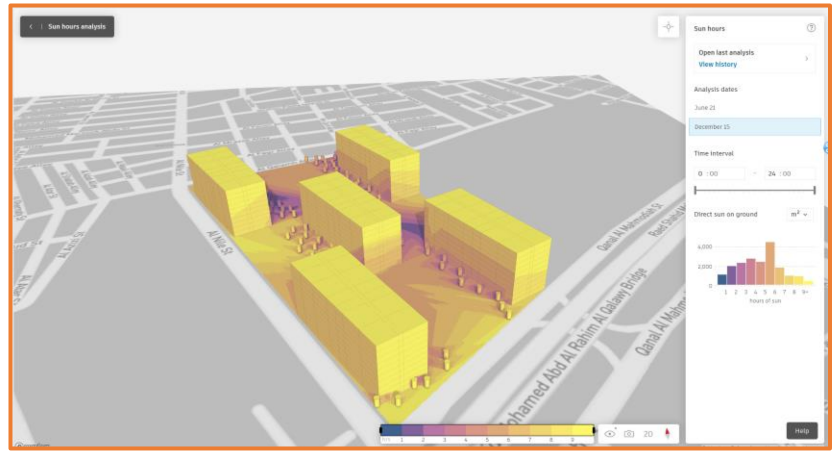
In the scope of generative design tools that aid in sustainability analysis, **Autodesk Forma** and **Finch 3D** stand out for their features tailored to enhancing environmental sustainability of housing projects.

Autodesk Forma

Autodesk Forma supports sustainability analysis by:

- Offering advanced simulation tools that model sunlight exposure, wind patterns, and energy consumption, Autodesk Forma enables architects to design buildings that optimize natural resources and minimize energy use.
- It provides tools for selecting sustainable materials and construction techniques, helping to reduce the environmental footprint of new housing developments.
- By integrating with BIM, Autodesk Forma ensures that sustainability considerations are woven into every stage of the design and construction process, facilitating informed decision-making that balances aesthetic, functional, and environmental objectives.

The capabilities of Autodesk Forma in sustainability analysis ensure that mass housing projects can achieve high standards of environmental responsibility, making them more appealing to environmentally conscious residents and contributing to broader sustainability goals.



This screenshot from Autodesk Forma demonstrates its capability for environmental analysis, specifically showing a solar hours analysis. The interface displays a 3D model of a building complex overlaid with a heatmap indicating the distribution of sunlight exposure over time. The tool allows users to set analysis parameters, view results by time intervals, and interpret data through histograms, facilitating informed design decisions based on solar performance, (source:author)

5.Design and Development

The Design Development Phase is a critical stage in mass housing projects where initial concepts are refined into detailed, actionable plans. This phase involves the intricate detailing of floor plans, elevation designs, material specifications, and integration of structural and MEP (mechanical, electrical, and plumbing) systems, all while adhering to budgetary constraints and regulatory requirements. The focus is on transforming visionary ideas into practical, buildable designs that meet the diverse needs of future residents and comply with sustainability standards. In this context, generative design tools like **Planfinder**, **Homestyler**, and **Finch 3D** prove invaluable, offering advanced functionalities tailored to the demands of design development.

5.1.Planfinder

Planfinder excels in automating the generation of detailed floor plans that comply with building codes and project-specific constraints, making it an essential tool for the design development phase. Its capabilities include:

- Quickly produces efficient and code-compliant layout options, substantially reducing manual drafting time and accelerating the design process.
- Allows for easy adjustments to layouts to accommodate specific design requirements or resident preferences, ensuring that the final plans are both practical and personalized.

5.2.Homestyler

Homestyler stands out for its intuitive interface and broad design capabilities, catering especially to interior layouts and detailing. Its strengths in the design development phase include:

- Offers immersive visualization tools that enable designers and stakeholders to explore interior spaces interactively, enhancing decision-making and client satisfaction.

- Provides access to vast libraries of materials, finishes, and furnishings, supporting detailed specification and customization of interior environments.

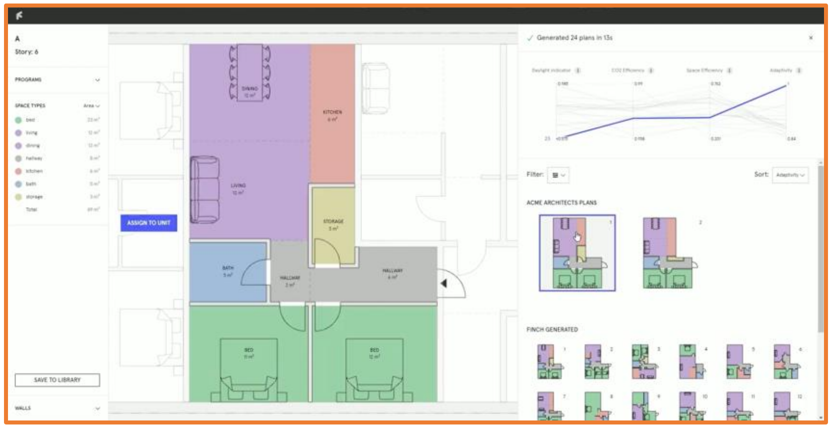
This screenshot features Homestyler. The interface includes a detailed floor plan with tools for customizing full house furnishings, wall settings, and floor settings. Users can easily add adjust rooms layout, apply different materials, and adjust room openings. The tool also provides various view options, enhancing the design and visualization process for residential interiors., (source:author)

5.3.Finch 3D

Finch 3D contributes to sustainability analysis by:

- Leveraging parametric design capabilities, Finch 3D enables the exploration of design variations that respond to floor plan generation constraints, enhancing energy efficiency and resident comfort.

- Finch 3D is particularly strong in generating optimized residential floor plans. Leveraging advanced parametric design capabilities, Finch 3D enables architects to explore a variety of design variations that respond effectively to constraints, enhancing both functionality and resident comfort. By allowing rapid generation and iteration of different floor plan options, Finch 3D ensures that spatial layouts are highly efficient and tailored to meet diverse user needs.



This screenshot showcases Finch 3D. The interface displays a detailed floor plan with color-coded spaces, options to assign rooms to units, and various filters for customization. It features analytical charts and multiple generated plan options, demonstrating the tool's efficiency in creating and evaluating numerous design iterations quickly. (Source, author)

6.Visualization and Inspiration

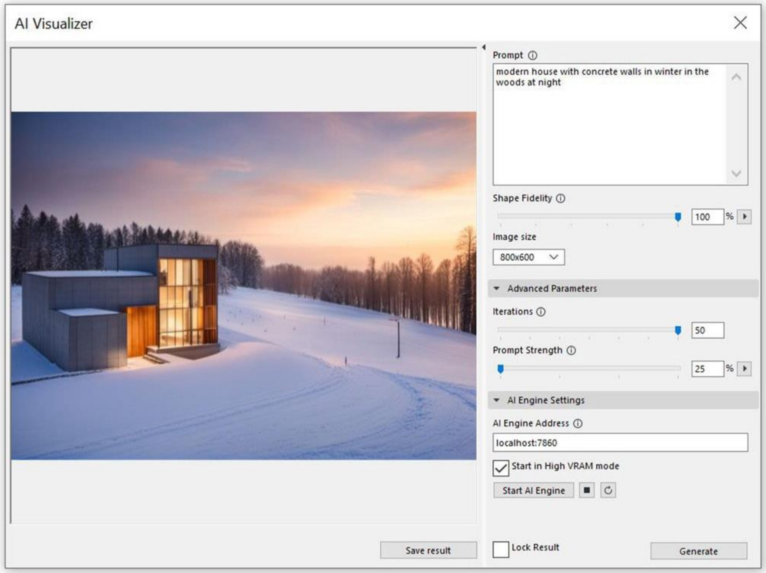
The Visualization and Inspiration Phase in mass housing projects plays a crucial role in bridging the gap between conceptual designs and their realization, facilitating stakeholder engagement, and refining final design details. This phase leverages advanced visualization tools to convey architectural concepts in an immersive, comprehensible manner,and sparking inspiration. In this context, tools like AI Visualizer, LookX.AI, Mnml.AI, alongside Midjourney and Dall-E for broader creative inspiration, stand out for their capabilities.

AI Visualizer and **Veras** are specifically designed to support architectural visualization, offering features that translate complex architectural models into vivid, lifelike representations:

6.1.AI visualizer and Veras

- Both tools excel in generating high-quality 3D visuals that accurately reflect the architectural intent, materials, and spatial qualities of design proposals, making it easier for non-technical stakeholders to visualize and engage with the design concepts.

- AI Visualizer and Veras enable rapid adjustments to visualizations based on text inputs/prompts by the users, supporting an iterative design refinement process. This adaptability ensures that the visualizations evolve with the design, maintaining alignment with project goals and stakeholder preferences.



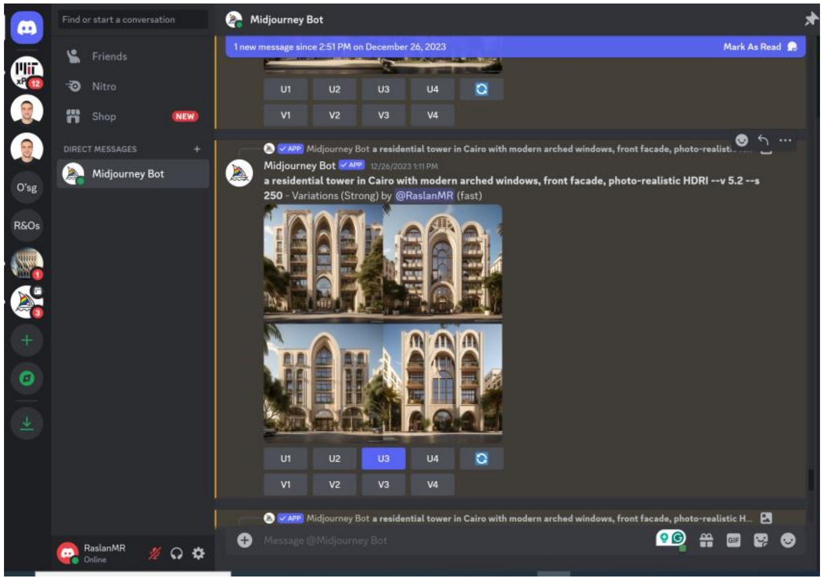
This screenshot from AI Visualizer, an AI add-on for Archicad powered StableDiffision image generation model, shows the interface used for generating architectural visualizations. The interface includes controls for shape fidelity, image size, advanced parameters like iterations and prompt strength, and AI engine settings, providing users with customization options to refine the visual output. (source, Graphisoft.com)

6.2.Midjourney and Dall-E

For more general creative inspiration, **Midjourney** and **Dall-E** offer generative capabilities that extend beyond conventional architectural visualization:

- By processing textual descriptions, these tools can generate a wide range of imagery that can inspire architectural design, from abstract concepts and mood boards to more tangible design elements and environmental settings.
- They serve as invaluable resources for exploring design aesthetics, conceptual themes, and innovative solutions that might not emerge through conventional design processes, providing a fresh perspective on mass housing customization.

Incorporating tools like AI Visualizer, Veras, Midjourney, and Dall-E into the visualization and inspiration toolkit empowers architects and designers to deliver their visions effectively, engage stakeholders meaningfully, and explore new fields of creativity.



This screenshot from Midjourney showcases the interface for generating variations of architectural designs using AI. The specific example depicts a residential tower in Cairo featuring modern arched windows and a photo-realistic front facade. Users can view and generate more iterations from design variations, indicated by the options for variantions (V1, V2, etc.) and upscaling (U1, U2, etc.), allowing for interactive refinement of the generated images. (source: author)

Appendix 2: Interview with Mass Housing Professionals

1.Interview Questions

The following questions are intended for interviews with professionals in the mass housing sector. They aim to gather insights about the challenges in mass housing development and expectations for a generative design toolkit.

1.1.Background and Experience

Could you provide an overview of your professional background and experience in mass housing projects?

What types of mass housing projects have you been involved in, and in what roles?

1.2.Challenges in Mass Housing Projects

What are the most significant challenges you have encountered in designing or developing mass housing projects?

Could you describe a particularly challenging project and how you managed its complexities?

1.3.Design and Planning Phase

What are the typical design phases that your office follows for mass housing projects? What is the average time spent on each phase?

Are there any aspects of the design process that you consistently find challenging?

1.4.Customization and User Needs

Do you include potential residents preferences in you designs? And how?

Can you share experiences or perspectives on addressing diverse resident needs in these projects?

1.5.Role of Technology and Tools

What role does technology currently play in your design and planning processes?

Are there specific software or tools that you find indispensable in your work?

1.6.Expectations from a Generative Design Toolkit

Are you familiar with any of the generative design tools on the market?

What essential features would you expect in a generative design toolkit (set of tools) for mass housing?

How do you envision such a toolkit enhancing your workflow or addressing common challenges?

How important is scalability in your projects, and what role could a design toolkit play in this regard?

How important is software integration in your work, and what specific integrations would you find valuable?

1.7.Sustainability and Environmental Considerations

How is sustainability integrated into your mass housing projects?

What features in a design toolkit would aid in enhancing the sustainability of these projects?

The purpose of these questions was to enable in-depth talks, providing qualitative data for the research and guiding the development of the generative design toolkit.

2.Interviews Procedure and Transcript
Participant Recruitment and Privacy Protocol

2.1. Identification of Participants
A meticulous identification procedure was carried out to acquire significant views from professionals in the field of mass housing, such as architects, urban planners, and project managers. The potential participants were obtained through industry associations, professional networks, and relevant profiles within the sector.

2.2. Initial Contact and Informed Consent
After identifying the participants, we contacted them with customized invitations that clearly explained the goal of the research, emphasized the importance of their expertise, and invited them to participate in an interview. Every invitation contained an in-depth explanation of the research's objectives, the anticipated duration of involvement, and the precise subjects that would be addressed. In addition, the importance of voluntary participation and the freedom to exit without facing any negative outcomes were highlighted to guarantee informed consent.

2.3. Privacy Policy Discussion
Upon initial contact, participants were given a detailed privacy policy. This policy clearly stated that any contact information collected will be maintained in strict confidence. In addition, the participants were guaranteed

that their complete names would not be revealed in any publication or report resulting from the research. In order to provide additional protection for their identity, any quotations used in the study would be anonymized.

2.4. Scheduling and Logistics

After obtaining consent, the interviews were scheduled, providing participants with varied timing options to fit their availability. The interview format (in-person, phone, or video) was explained, and any essential technical specifications were given to guarantee a smooth procedure.

2.5. Conducting the Interview

The interviews were performed in a professional manner, following the agreed-upon themes and keeping an open and courteous discourse. Participants were urged to openly share their views and experiences, offering a collaborative and instructive conversation.

Appendix 3: Mass Housing challenges and generative design potential survey

The survey data include replies from 58 architects in the housing industry concerning the obstacles faced in mass housing and the utilization of generative design technologies. Below are a few of the questions that were given to the participants:

How many years of experience do you have?
What is your job title?

How often do you work on mass housing projects?
What are the typical design phases of any mass housing project you do?
What is the number of iterations typically made during the conceptual design process?
Do you perform feasibility studies for the housing projects?
Do you perform sustainability analysis?
What specific aspects of sustainability are considered?
How sustainability is integrated into projects?
Are you familiar with generative design tools related to housing design?
Do you use any generative design tools?
How do you use the generative design tools and in which process?
What are the challenges faced when adopting generative design tools?

Appendix 4: Potential residents preferences survey questions

All the questions distributed, and the answers received were in Arabic, as the purpose of this survey was to collect data for the case study.

4.1.Unit Size and Layout Preferences

What is your preferred unit size (area in m2)?

How many rooms do you prefer in your housing unit?

Do you prefer to own or rent an apartment?

If you prefer to own the housing unit, what is the expected affordable price you would pay?

If you prefer to rent an apartment, what is the expected affordable price you would pay?

If you knew that the average price for these apartments is as follows, which apartment size would you buy?

If you knew that the average rent price for these apartments is as follows, which apartment size would you rent?

Do you prefer having large windows and natural light in your living space?

Do you prefer any specific arrangement of the rooms?

Do you prefer an open kitchen layout?

Do you need any flexible spaces that can be adapted for remote work?

Do you prefer a balcony or a large window?

How important is it to have storage space in your housing unit?

On which floors do you prefer to live?

How important is it to have private outdoor space (e.g., balcony, patio)?

4.2.Community Amenities and Transportation

How important are community gardens and social spaces to you?

How important is access to the public transportation network for you?

How important is it to have parking spaces available in your housing complex?

How important is it to have recreational facilities (e.g., gym, pool) in your housing complex?

Unit Size and Location Preferences

What is your preferred unit size?

On which floors do you prefer to live?

How important is it to have private outdoor space (e.g., a garden, patio)?

4.3.Demographics of Respondents

How old are you?

How many people live in your household?

What is your marital status?

How many children do you have?

How many boys or girls do you have?

Do you have a pet?

What is your highest level of education?

Acknowledgements

I would like to express my deepest gratitude to my direct supervisor, Dr. Bartók István, for his invaluable guidance and direction throughout the four years of my study, and especially during the two years of thesis supervision. His insightful feedback and continuous support have been contributory to shaping this research.

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I am profoundly grateful to my wife, whose unwavering support, patience, and understanding have been my greatest source of strength throughout this journey. Her encouragement and belief in me, even during the most challenging times, have been invaluable. To my daughter, whose curiosity and joy have been a constant reminder of the beauty of discovery, and to our baby on the way, who has been an unexpected yet wonderful source of motivation as I completed this dissertation, thank you for inspiring me in ways words cannot fully express.

Finally, I would like to thank all those who have contributed to my research and supported me in various ways during this journey. Your encouragement and assistance have been greatly appreciated.

A transitional stage in the Bashayer El-Kheir housing project, where newly constructed high-rise residential buildings starkly contrast with the remnants of informal settlements (photo taken by author)

Scan the QR code to listen to a podcast about the dissertation

Generative Design for the Masses: A Toolkit for Customized Housing

Mohamed Raslan Doctoral Dissertation

Budapest University of Technology and Economics

Doctoral School of Architecture

Budapest, 2025