University of Cyprus
Department of Architecture

METARCHITECTURE

RETHINKING ARCHITECTURAL DESIGN PROCESS USING INTEGRATED PARAMETRIC DESIGN AND MACHINE LEARNING PRINCIPLES

Diploma Thesis of Integrated Master Degree **M.Arch**

Alexis Andreou
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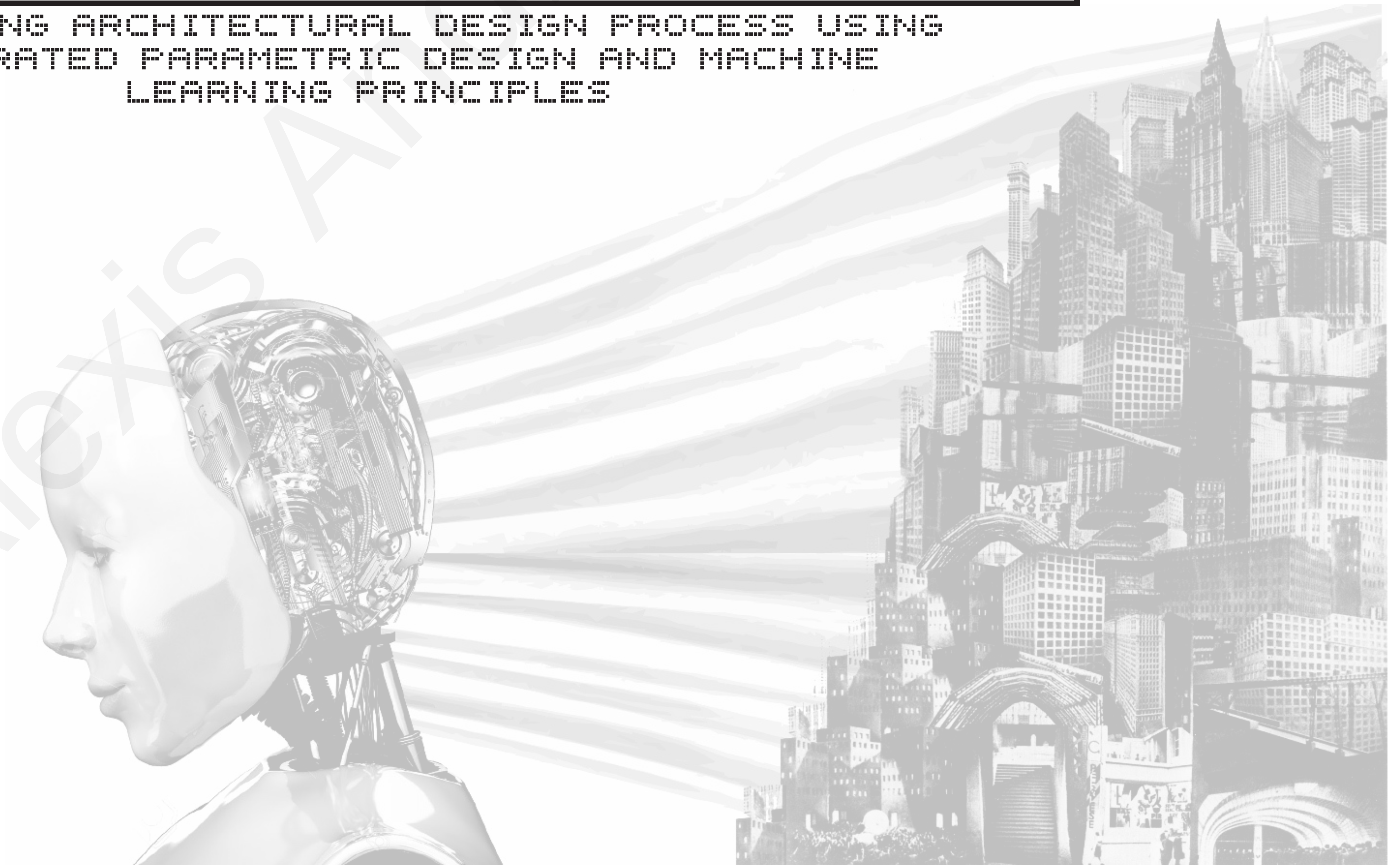

ΕΠΙΒΛΕΠΟΝΤΕΣ ΚΑΘΗΓΗΤΕΣ ΔΙΠΛΩΜΑΤΙΚΗΣ:

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Υπογραφή

[redacted]

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ABSTRACT

Artificial Intelligence (AI) has the potential to process vast amounts of subjective and conflicting information in architecture. However, it has mostly been used as a tool for managing information rather than as a means of enhancing the creative design process. This work proposes an innovative way to enhance the architectural design process by incorporating Machine Learning (ML), a type of AI, into a parametric architectural design process. ML would act as a mediator between the architects' inputs and the end-users' needs. The objective of this work is to explore how Machine Learning (ML) can be utilized to visualize creative designs by transforming information from one form to another - for instance, from text to image or image to 3D architectural shapes. Additionally, the aim is to develop a process that can generate comprehensive conceptual shapes through a request in the form of an image and/or text. The suggested method essentially involves the following steps: Model creation, Revisualization, Evaluation. By utilizing this process, end-users can participate in the design process without negatively affecting the quality of the final product. However, the focus of this approach is not to create a final, fully-realized product, but rather to utilize abstraction and processing to generate a more understandable yet minimal outcome which will have the capability to receive an evaluation.

Η Τεχνητή Νοημοσύνη (ΤΝ) έχει τη δυνατότητα να επεξεργαστεί μεγάλες ποσότητες υποκειμενικών και αντιφατικών πληροφοριών στην αρχιτεκτονική. Ωστόσο, έχει χρησιμοποιηθεί κυρίως ως εργαλείο για τη διαχείριση των πληροφοριών παρά ως μέσο ενίσχυσης της δημιουργικής διαδικασίας σχεδίασης. Αυτή η εργασία προτείνει έναν καινοτόμο τρόπο ενίσχυσης της αρχιτεκτονικής διαδικασίας σχεδίασης με την ενσωμάτωση της Μηχανικής Μάθησης (ΜΜ), είδος (ΤΝ), σε μια παραμετρική αρχιτεκτονική διαδικασία σχεδίασης. Η ΜΜ θα λειτουργούσε ως μεσολαβητής μεταξύ των εισροών του αρχιτέκτονα και των αναγκών του τελικού χρήστη. Ο στόχος αυτής της εργασίας είναι να εξερευνήσει πώς η Μηχανική Μάθηση (ΜΜ) μπορεί να χρησιμοποιηθεί για να οπτικοποιήσει δημιουργικές προτάσεις σχεδιασμού μετατρέποντας πληροφορίες από μια μορφή σε μια άλλη - για παράδειγμα, από κείμενο σε εικόνα ή από εικόνα σε τρισδιάστατα σχήματα. Επιπλέον, στόχος είναι να αναπτυχθεί μια διαδικασία που μπορεί να δημιουργήσει συνεκτικά εννοιολογικά σχήματα μέσω μιας μέσω αιτήματος με τη μορφή εικόνας ή/και κειμένου. Η προτεινόμενη μέθοδος περιλαμβάνει ουσιαστικά τα εξής βήματα: Δημιουργία μοντέλου, Επαναοπτικοποίηση, Αξιολόγηση. Χρησιμοποιώντας αυτήν τη διαδικασία, οι τελικοί χρήστες μπορούν να συμμετάσχουν στη διαδικασία σχεδίασης χωρίς να επηρεάζουν αρνητικά την ποιότητα του τελικού προϊόντος. Ωστόσο, ο κύριος στόχος αυτής της προσέγγισης δεν είναι να δημιουργήσει ένα τελικό, πλήρως υλοποιήσιμο προϊόν, αλλά να χρησιμοποιήσει την αφαίρεση και μέσω επεξεργασίας να δημιουργήσει ένα κατανοητό αποτέλεσμα που θα εμπεριέχει όλα τα ελάχιστα ούτος ώστε να έχει τη δυνατότητα να λάβει αξιολόγηση.

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INTRODUCTION

This thesis project draws inspiration from a deep personal concern and interest in various aspects of architecture's creation and development, particularly in the context of modern technological advancements, including the new industrial revolution and the rapid approaching emergence of Artificial General Intelligence (AGI) [1,2,3]. The project delves into the multidisciplinary nature of the architectural field and profound impact of modeling skills on the conceptual decision-making process in architecture, emphasizing the pivotal role they play in shaping innovative and visionary designs. Overall, this project aims to contribute to a comprehensive understanding of the challenges and opportunities that lie ahead in the rapidly evolving architectural landscape.

To begin with, by accepting the multidisciplinary nature of architecture, we should also accept a wide range of environments that the modern man is related to, such as natural, social, cultural, economic, digital etc. as an integral part of the design.

After that, we can observe that those environments as products of human activity (beside natural), are constantly changing and growing along with population and technology development at a rate that humans cannot respond to [4, 5].

In simple terms, as technology continues to advance, the volume of available information expands exponentially (also described as 'Information explosion' [6, 7] and 'knowledge avalanche' [8]). Consequently, it becomes increasingly challenging to attain a comprehensive understanding for making conceptual decisions on a large scale (Fig. 1). Thus, leveraging technological capabilities becomes crucial in the design process as an extension of our own capabilities. In that same way we interact with our devices, something that Andy Clark and David Chalmers describe as prosthetic extension of our minds, rather than just auxiliary elements [9].

Notably, the issue extends beyond architecture and permeates nearly every specific field. Consequently, various forms of Artificial Intelligence (AI), among other technologies, have emerged as key enabling technologies (also known as 'general-purpose technology' [10]) for advancing technological development and information handling in alignment with the new industrial revolution, commonly known as Industry 4.0 [11,12], since 2011 (Fig. 2). The Hype Cycle of AI technologies [13, 14] effectively illustrates the dynamic nature of progress in this direction, including forecasts for the attainment of a plateau in each individual technology (Fig. 3). Moreover, the concept of Society 5.0 [15, 16], initially presented by the Japanese government in 2016 (Fig. 4), delineates a socio-economic and cultural strategy for societal development based on the pervasive use of digital technologies across all spheres of life. This strategy envisages the integration of AI as a pivotal component to streamline the ensuing digital chaos, promising the realization of a forward-looking society that transcends existing stagnation, fosters mutual respect among its members transcending generations, and enables each individual to lead an active and fulfilling life.

Hence, the primary objective of this thesis is to explore the potential of leveraging AI to enhance the architectural synthetic process, aiming to offer a diverse range of solutions derived from participatory and parametric design convergence, driven by user feedback. This will be achieved through a comprehensive examination of the evolving correlation between design and technological advancements, considering contemporary and upcoming technological capabilities.

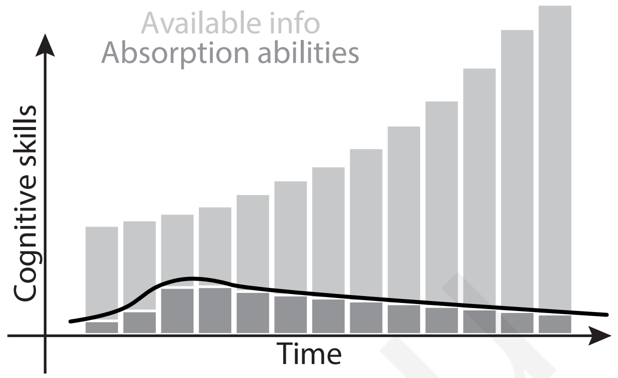


Figure 1: Neuroplasticity with the passing of time

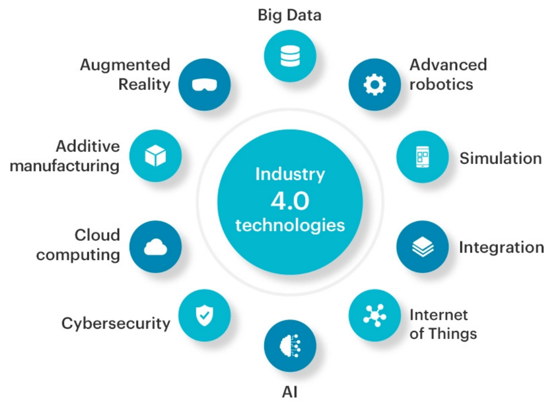


Figure 2: Industry 4.0 structure

(Source: "AuraQuantic" company website [11])

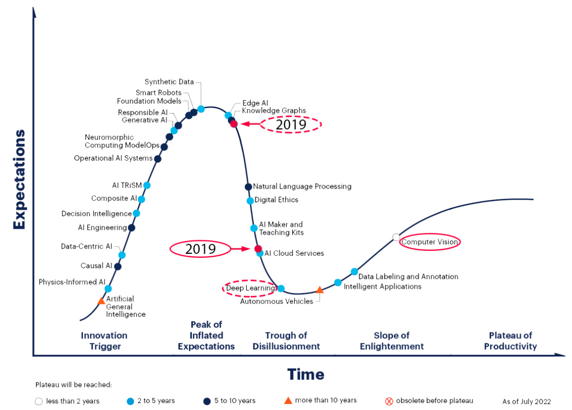


Figure 3: Hype Cycle 2019 & 2021 comparison

(Source: "Gartner" company website [13, 14])

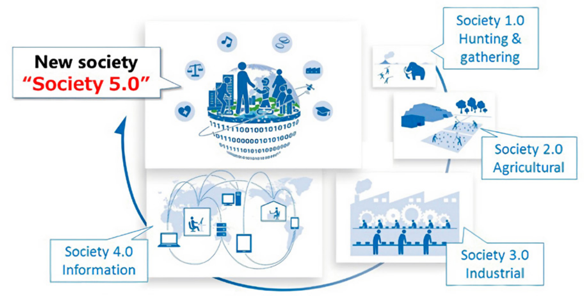
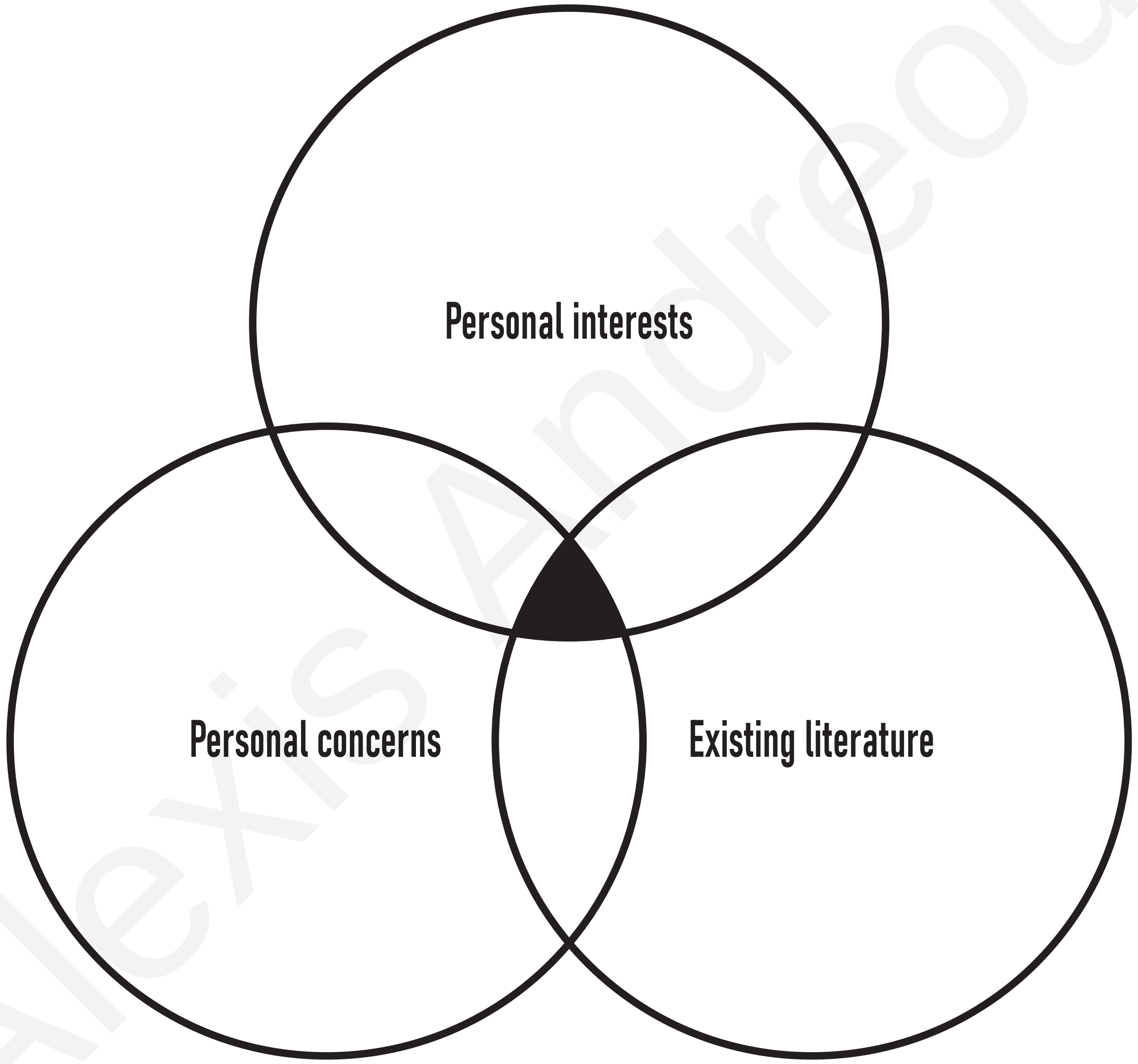


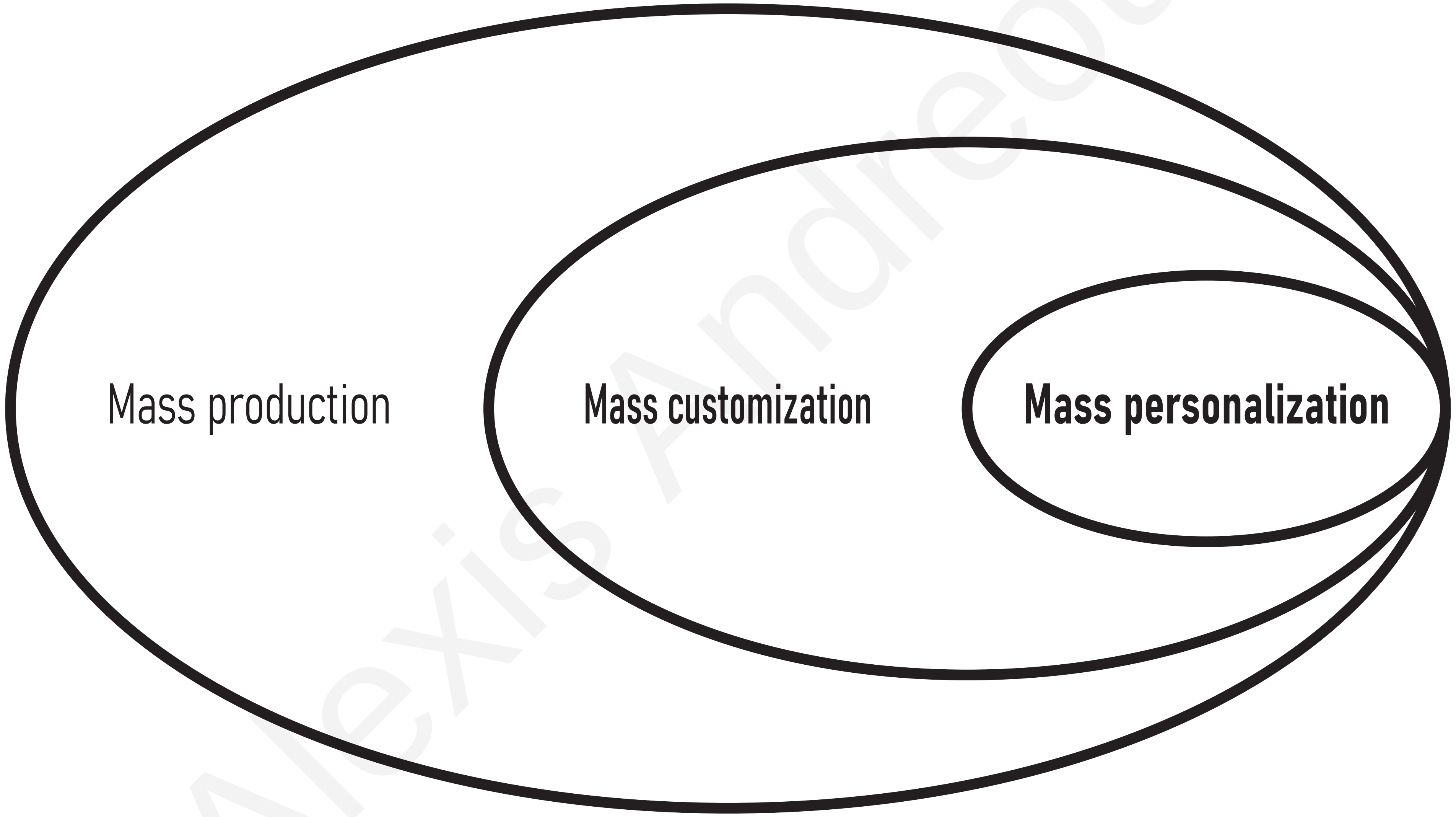
Figure 4: Society 5.0

(Source: "Cabinet Office of Japan" website [15])

THEORETICAL RESEARCH


Personal interests
Personal concerns
Existing literature

MASS CUSTOMIZATION


Mass production
Mass customization
Mass personalization

MASS VS MASSIVE

By exploring the intersection of design and technology, this chapter serves as a fundamental exploration of the concept of mass customization [17] in architecture, due to its significance as a groundbreaking approach to address the increasing demand for personalized and unique design solutions. This chapter serves as a crucial starting point for subsequent proposal formation as it highlights the significance of leveraging technological capabilities to enhance the design process.

Massive customization is a contemporary technological capability made possible by advancements in digital design and production technologies. On the other hand, mass customization is a contemporary business and marketing approach that aims to meet the distinct requirements of individual customers without a corresponding increase in cost. It necessitates social and cultural conditioning so that customers, whether they are purchasing furniture, cars, or even houses, can request and anticipate something unique rather than a standardized, mass-produced product. Another distinction between massive customization and mass customization lies in the ability to connect product features with contextual elements. Merely generating random design variations is insufficient; it is crucial that such variations arise from a thoughtful interpretation of the design context. This interpretation encompasses the physical, technological, cultural, and social context, as well as the individual circumstances of the user.

Meanwhile, mass personalization goes beyond massive and mass customization. While both strategies try to produce unique products with near mass production efficiency, “mass personalization aims at a market segment of one while mass customization at a market segment of few [18]” (Fig. 5). Not marketing but customering. Whereas customering means that each customer is an individual with unique and distinct needs and desires.

The concept of mass customization in architecture has been further enhanced by the ability to encode design instructions and materialize outputs through digital fabrication technologies. Today, building projects are not only conceived digitally but also realized digitally through a ‘file-to-factory’ process utilizing CNC fabrication. While parametric design can account for dimensional, color, and texture variations, rule-based design systems, such as shape grammars, enable the incorporation of topological variation. Although implementing rule-based design systems may encounter shape recognition challenges, converting them into parametric design models can facilitate computer implementation.

Parametrically defined and interactively designed mass-customizable houses can be digitally prefabricated using the file-to-factory process. While this technological and economic feasibility exists, there are social and cultural considerations that need to be addressed. One particularly compelling aspect of mass customization in house designs based on parametric variation is the potential to achieve homogeneous heterogeneity at the neighborhood scale. This means that while the houses may exhibit typological and topological similarities, their layout and geometry can vary significantly. This mimics the characteristics of traditional and historic neighborhoods, where overall stylistic or formal unity is maintained while allowing for differences in individual elements.

Thus, the challenges in the broader adoption of interactively customizable house designs are primarily social and cultural rather than technological (Fig. 6). Therefore, addressing these challenges will be crucial for embracing the potential of mass customization in architecture.

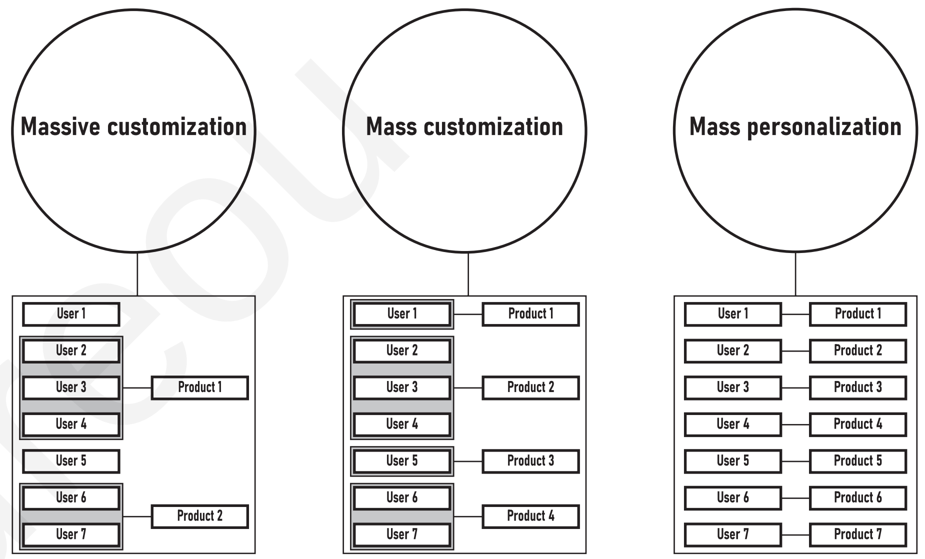


Figure 5: Classification of approaches

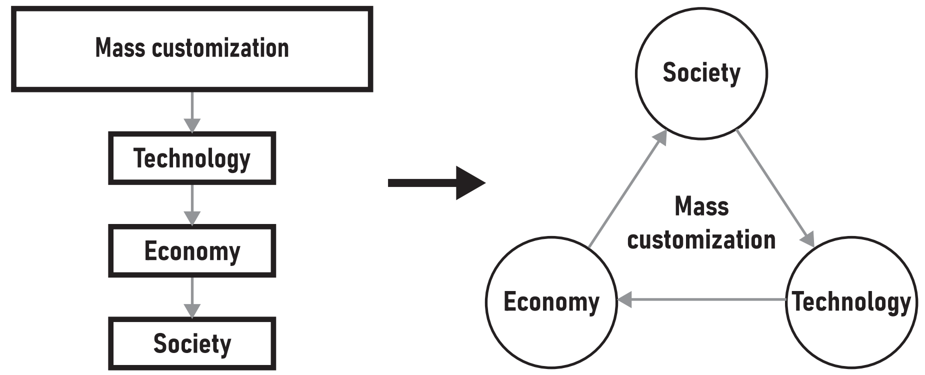


Figure 6: Concept workflow revision

IMPLEMEINTATION EXAMPLES

MASS VS MASSIVE

'Objectile' [19], conceived by Bernard Cache and Patrick Beaucé in 1997, is a historically remarkable example that explores the principles of mass customization. This innovative approach revolutionizes traditional construction methods by introducing the ability of variability generation via parametric interface. Objectile employs a series of geometric elements that can be assembled in numerous configurations, allowing for the creation of unique and personalized architectural structures (Fig. 7). The system's modularity enables designers and non-designers to set the form, size, and functionality to meet specific requirements. By integrating the principles of mass customization, Objectile challenges the notion of standardized architecture and embraces a more inclusive and responsive design process. This project not only pushes the boundaries of parametric design but also emphasizes the importance of customization in creating spaces that truly address the diverse needs and desires of individuals and communities.

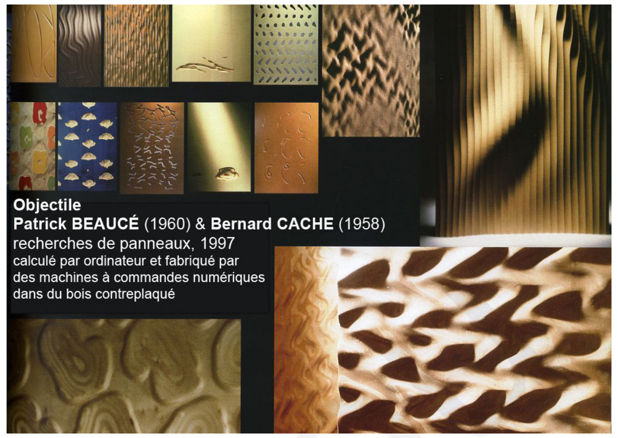


Figure 7: Objectile
(Source: "overblog" blog [20])

'mTable' [21], designed by Fabio Gramazio and Matthias Kohler in 2005, is another approach that exemplifies the concept of mass customization. This innovative approach combines digital fabrication techniques with customization ability, allowing users to tailor its design to their specific preferences. mTable harnesses the power of computer numerical control (CNC) milling to create unique, personalized tabletops by modifying the geometric patterns and profiles (Fig.8). By offering a range of customization options, such as size, shape, and material, mTable blurs the boundaries between mass production and individual expression. Even with very short and limited list of available parameters, this project not only showcases the potential of digital fabrication technologies, but also challenges traditional notions of standardized furniture, paving the way for a more personalized and inclusive design approach.

Figure 8: mTable
(Source: "Gramazio Kohler" website [21])

'DesignYourOwnHome' [22], developed by Toll Brothers, Inc. in 2005, is a platform (Fig, 9) that exemplifies the concept of mass customization within the realm of residential architecture. This innovative for its time online tool empowers homebuyers to personalize and customize various aspects of their future homes, allowing them to design a living space that aligns with their unique preferences. Through this platform, users can select from a range of floor plans, architectural styles, finishes, and additional features, tailoring their dream home to suit their specific needs. By combining a user-friendly interface with a vast array of customizable options, Toll Brothers have transformed the traditional home-buying experience, offering a level of personalization that goes beyond mere interior design choices. This pioneering approach not only enables homeowners to adapt the living spaces in accordance with their individuality, but also highlights the significance of mass customization in creating truly personalized and satisfying living environments.

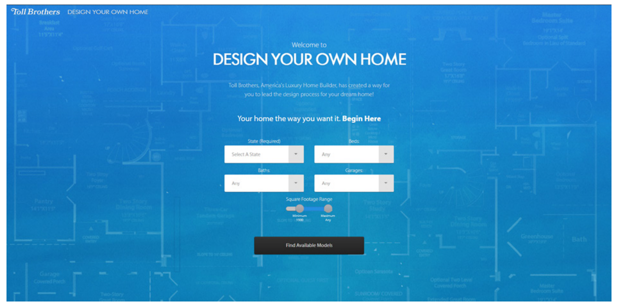
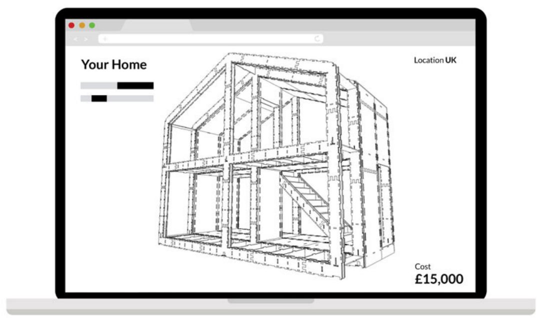


Figure 9: DesignYourOwnHome
(Source: "Toll Brothers" website [22])

'Wikihouse' [23], a startup founded in 2011, is one of the most recent and groundbreaking initiatives that exemplifies the concept of mass customization in the realm of construction and architecture. This platform (Fig. 10) leverages the power of open-source design and digital fabrication technologies to enable individuals to design, share, and construct their own homes. Wikihouse provides a library of customizable architectural designs that can be downloaded, modified, and fabricated using CNC milling machines. By offering an accessible and collaborative platform, Wikihouse democratizes the process of homebuilding, allowing individuals with little to no technical expertise to actively participate in the creation of their living spaces. This disruptive approach challenges traditional construction methods and fosters a culture of sharing, innovation, and sustainability. Wikihouse not only empowers individuals to create personalized homes but also promotes the idea of a more inclusive and environmentally conscious future of architecture.

Figure 10: Wikihouse
(Source: "urbanNext Lexicon" publishing house [23])



ROLE OF USER

The biggest and most important challenge in the development of the customization system is to set the balance between what is defined by the designer and what is left for the product user to decide. Increasing the amount of choice available to the user increases the opportunity for mass customization, but it also may represent a risk to design quality. In systems that are too open, it may be difficult or even impossible to foresee or detect combinations of variable values that may result in bad solutions from a functional or esthetic viewpoint. In addition, some users might feel overwhelmed with the burden of choice and not be interested in becoming the “designers”.

There is also the challenge concerning the user interface. If the decision to empower the user with a high degree of freedom is made, one still has to find appropriate ways for the user, potentially a non-designer, to understand what is at stake and make informed decisions. Based on the work of economist Herbert A. Simon called bounded rationality [24], a human decision-making process attempts to satisfy, rather than optimize. In other words, we seek a decision that will be good enough, rather than the best possible decision, leading us to choose inconsistently.

Since we are limited by brain capacity (partially due to cognitive biases), time and available information, we have to make decisions using shortcuts (labels). These shortcuts make it easier for us to make decisions, but they challenge our ability to be rational, sometimes leading us to make suboptimal choices just because we often don’t actually know what some terms mean, forming our decisions on a false sense of rationality. Various studies [25, 26, 27] indicate that our decisions are mainly influenced not so much by rationality as by other factors, whether it be convenience, the desire for immediate gratification, other cognitive biases.

Our choices are still rational, considering the information that is realistically available to us, but may not be rational in lieu of all the possible information and resources. However, different companies demonstrate that sometimes making compromising decisions is more effective rather than the purely economic oriented, meaning that bounded rationality is actually more effective than perfect rationality, because we live in a complex world that isn’t black and white when it comes to making decisions.

Summing up, it can be useful to get multiple opinions on what the best decision is. Working as a team helps us overcome bounded rationality because we lessen limitations; it provides us with multiple perspectives that are not all affected to the same degree by cognitive biases and gives us more time to learn about the possible alternatives in order to arrive at an optimal decision. This requires developing effective ways of communicating the meaning of more complex design variables to the user and then showing the impact of selected variable values. From fully automation to situations where the user of the systems makes the decisions with the system providing feedback by indicating the performance of the corresponding solution via simple interface.

The ‘D-Tower’ by NOX [28] and the ‘Network of Games’ (NoG) [29] by Play the City Foundation are noteworthy examples that explores the use of user feedback in architecture. These projects highlight the value of engaging users in the design process and utilizing their input to shape architectural outcomes. The D-Tower’s interactive displays, influenced by real-time data, enable users to actively participate in creating visual outputs (Fig.11). Similarly, NoG integrates digital and analog play (Fig. 12), allowing users to contribute their knowledge and data for analysis and decision-making. These projects highlight the crucial role of user involvement and feedback in shaping architectural design, emphasizing the importance of inclusive and participatory approaches in the field.

Figure 11: D-Tower

(Source: ARCHITECTUREGUIDE.NL website [28])

Figure 12: Network of Games

(Source: Play the City website [29])

PARAMETRICISM

Although, within the framework of mass customization, the term parametric design in a broad sense refers mostly to its ability to include topological and dimensional variation, as well as variation of other shape attributes, such as material, color, and texture. It is necessary to acknowledge that parametric design, as an approach, represents only one facet of Parametricism —a pioneering design approach and mindset that transcends mere architectural style [30]. Furthermore, by outlining some of the additional approaches encompassed by this concept, we can enhance our understanding of its inherent possibilities. For instance:

Algorithmic design: design that uses algorithms to generate and manipulate geometry based on a set of rules and parameters allowing for a high degree of control and flexibility

Generative design: a type of parametric design that uses algorithms to generate a matrix of results based on combinations of selected params and settings.

Interactive design: design based on real-time feedback and user input to shape and modify a design in response to user needs and preferences.

Multi-objective optimization: design based on multiple conflicting objectives (e.g., minimizing cost vs maximizing energy efficiency), and finding the best possible trade-offs among them.

Performance-driven design: a type of design that uses algorithms and simulation tools to optimize the performance of a design, such as energy efficiency, structural stability, or acoustics.

Data-driven design: a type of design that uses data analysis and visualization tools to inform and optimize the design process. It can include using data to inform site analysis, building performance analysis, and user behavior analysis, among others.

While all of these types represent powerful tools for designers to create complex and adaptable designs that can respond to changing conditions and user needs, they are still stand alone and/or are used as relatively simple combinations to solve partial needs depending on the specific goals, constraints, and criteria of the project. However, there is potential for them to be combined into a cohesive system that functions as a ‘generating system’ described be Christopher Alexander’s [31]. According to his general notion, such a system will usually consist of a kit of parts (or elements) together with rules for combining them to form allowable “things”. Meanwhile, any combination of parts which is not formed according to the rules is either meaningless or false.

Man as a designer focuses on designing and constructing cohesive objects. However, in the context of supporting vital aspects of urban life, holistic properties become essential. The solution lies in inventing generative systems that autonomously generate these holistic system properties. Thus, the designer’s role shifts to creating generating systems capable of producing multiple objects, instead of individual ones.

Nonetheless, not all generating systems naturally produce objects with valuable holistic properties. Unlike the animal forms, current building systems lack inherent cohesion, making them insufficient. A novel type of building system is required, one that is more nuanced and can generate buildings while ensuring their operation as holistic systems within the social and human context.

Significant examples within this context are: ‘Digital Grotesque I by Michael Hansmeyer & Benjamin Dillenburger (2013) [32] and ‘Synesthesia’ by Joris Putteneers (2016) [33, 34]. These works showcase an attempt to generate complete procedural 3D models using algorithmic capabilities. The resulting forms embody a unique combination of synthetic and organic qualities, existing at the intersection of chaos and order. The design process thus finds a delicate balance between the expected and the unexpected, as well as between control and relinquishment. Combining elements of the natural and the artificial, without being entirely foreign or completely familiar (Fig. 13-14).

Figure 13: Digital Grotesque I
(Source: “Michael Hansmeyer” website [32])

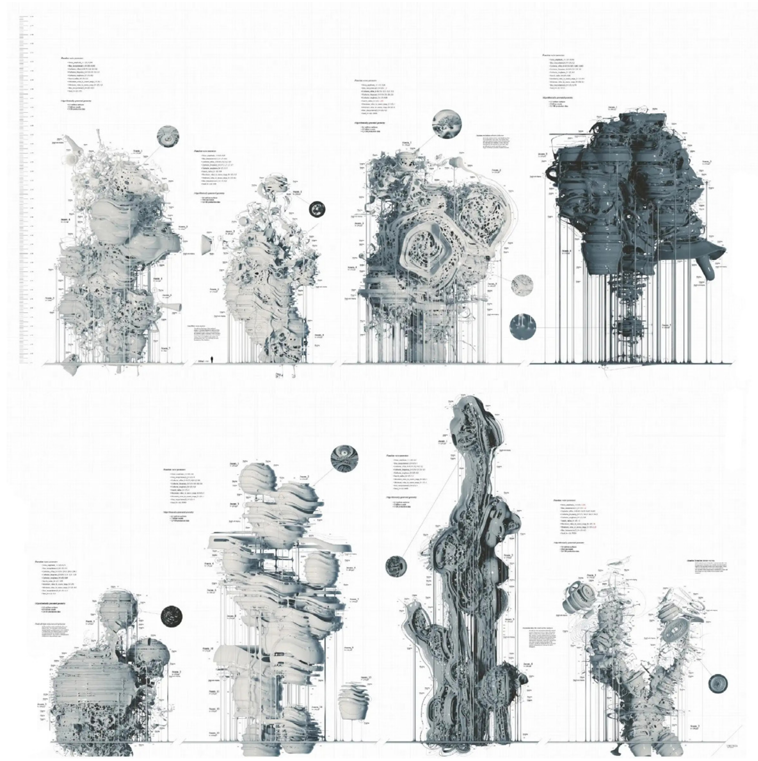
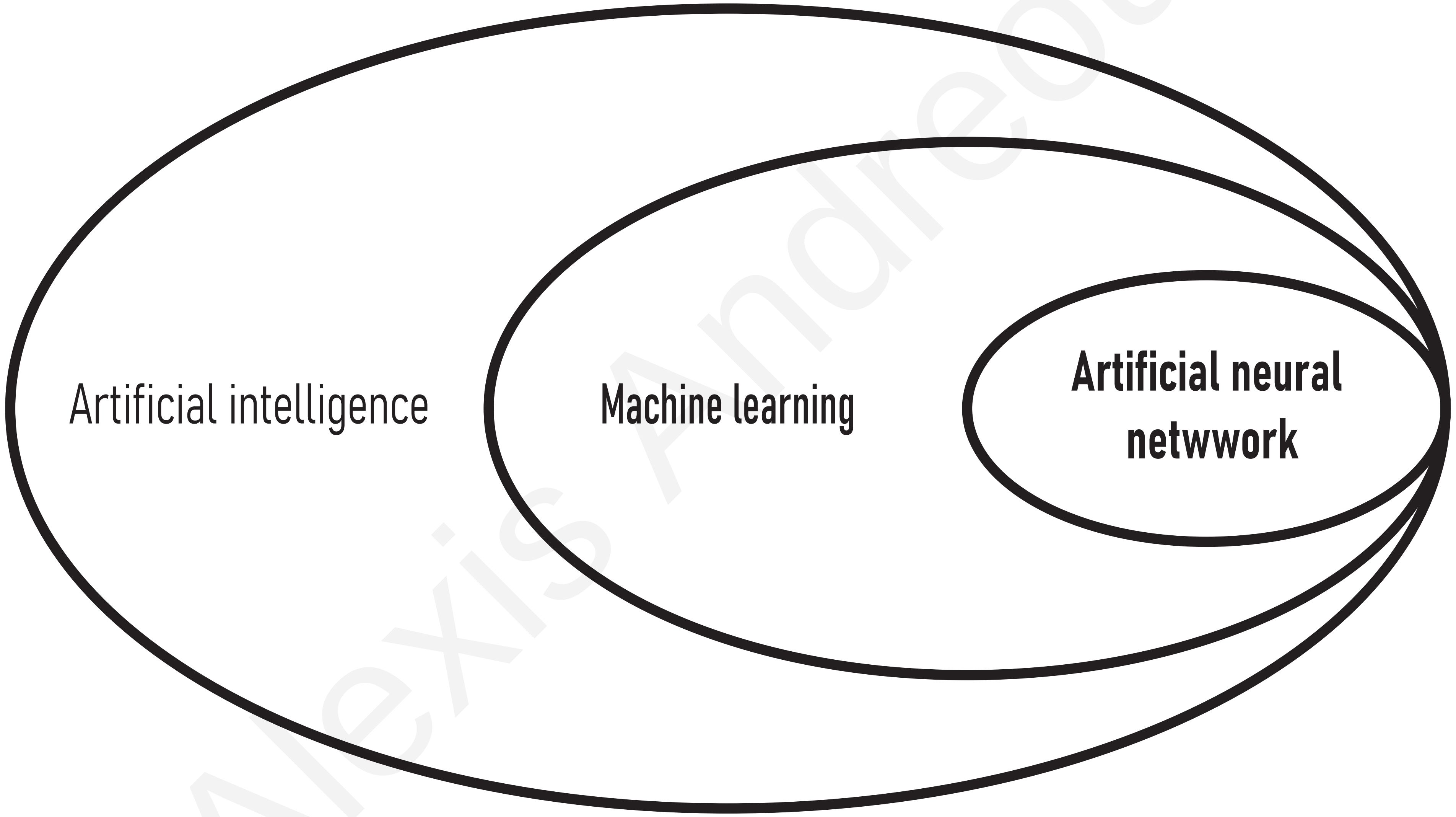


Figure 14: Synesthesia
(Source: “Medium” publishing platform [33])

ARTIFICIAL INTELLIGENCE


Artificial intelligence
Machine learning
Artificial neural
netwwork

ABOUT AI

AI is a term that may seem unfamiliar to architectural vocabulary; nevertheless, it is crucial to recognize that AI has become an integral background technology that permeates our modern society. The advancement of AI holds tremendous potential for a wide range of industries, including architecture. This chapter aims to explore the intersections of AI and architectural practice, in order to provide an integral proposal for its implementation based on its current capabilities and the opportunities that lie ahead. To begin with, it is important to address some misconceptions about AI due to the abundance of information surrounding it.

First, the term ‘AI’ represents a collection of distinct approaches, exemplified by machine learning (ML), artificial neural networks (ANN), and deep learning (DL), rather than a singular concept or entity (Fig. 15). Although the development of AI has a long history, it is challenging to attribute its creation to a single person or group. The concept of intelligent machines has been explored by philosophers and scientists for centuries, and the field of AI, as we know it today, has evolved through the contributions of numerous researchers and practitioners, including John McCarthy, Marvin Minsky, Herbert Simon, Warren McCulloch, and Walter Pitts, among others. Early machine learning models like Alan Turing’s “a-machine” [36] and Frank Rosenblatt’s “perceptron” [37] emerged in 1936 and 1957 respectively, but the field of machine learning, as we currently understand it, did not fully emerge until the 1980s (based on the significant growth of relevant literature production, publications of influential papers, and establishment of dedicated conferences in the field of machine learning during that period). Therefore, even at this early stage of modern generative approaches, we can observe impressive advancements.

Secondary, a literal interpretation of the common definition of AI, which states that it aims to mimic or simulate human intelligence [38], can be misleading regarding the capabilities of AI due to its overly generalized nature. While this statement is not entirely false, it fails to acknowledge that AI currently lacks consciousness. For example, while AI may outperform a human in a game of chess, it does not possess the awareness that it is engaging in a game. Typically, AI is involved in tasks related to learning and problem-solving, but not all of these tasks require true intelligence. Thus, John Kelleher provides a more accurate definition of AI as the “field of research focused on developing computational systems capable of performing tasks and activities that are typically associated with human intelligence” [39]. Nevertheless, this does not mean that AI cannot be creative. According to Chaillou in an article on Towards Data Science [40]: “ It seems that style permeates irrevocably the very essence of any generative process. This means that each model or algorithm will come with its flavor, its personality, its know-how.” In the long term, however, AI is likely to exceed the intelligence of the human mind as mentioned earlier because despite all the AI-powered tools, humans are still required to refine and approve any of the designs used.

To conclude, “machine learning” demonstrates striking similarities to human learning processes. Just as humans acquire knowledge through experience and adapt their behavior based on feedback, machine learning algorithms rely on data to refine their performance. In the context of object recognition, humans acquire the ability to identify objects by observing their distinct features, shapes, and patterns, forming a mental model for future recognition. Similarly, machine learning algorithms analyze extensive datasets, extracting patterns to differentiate objects and make accurate predictions. Through iterative improvement driven by exposure to data and feedback, both humans and machine learning algorithms enhance their recognition abilities. However, it’s important to acknowledge the differences. Humans possess complex cognitive abilities, emotions, and intuition, while machine learning algorithms operate on mathematical models without consciousness or emotional understanding (Fig. 16). By drawing this parallel, we can grasp the potential of AI systems to learn from data while appreciating the unique aspects of human intelligence.

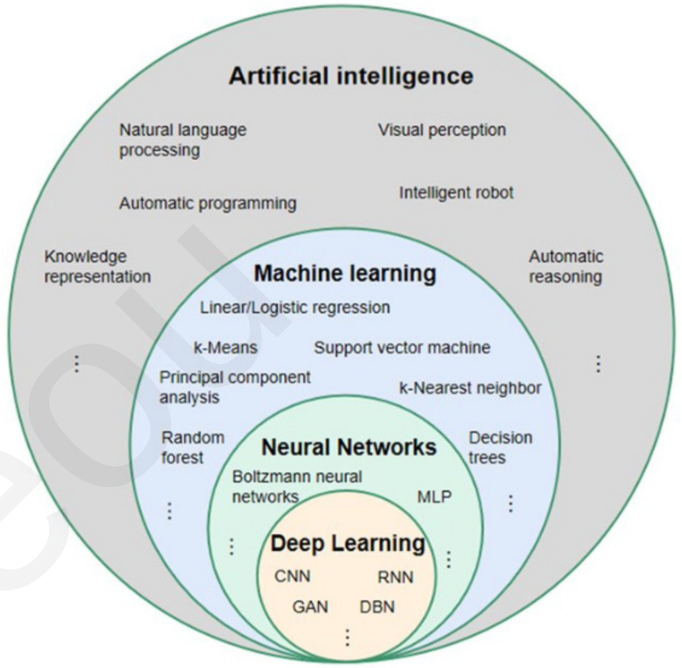


Figure 15: AI hierarchy classification
(Source: S. Li et al., 2021, p. 5 [36])

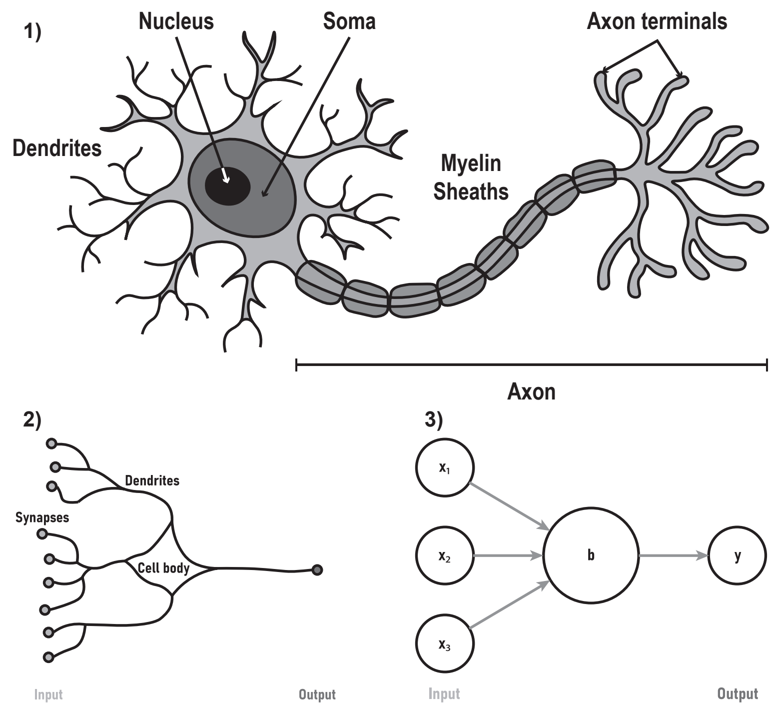


Figure 16: Neuron evolution from biological to artificial form
(1) Neuron; (2) Abstract model; (3) Perceptron

RELATED APPROACHES REVIEW

While there are numerous instances of AI being integrated into our daily lives, such as spam detection, image categorization, and user identification, these examples do not adequately showcase its potential contributions to the architectural field. Therefore, this thesis project focuses exclusively on exploring generative approaches as more appropriate representations of AI's capabilities within the architectural domain exploring AI's true potential and its impact on design.

In order to comprehend the subsequent research steps effectively, it is important to acknowledge that within the field of computer vision, generative approaches can be broadly categorized as combinations between "text", "image" and "model" such as: model2text, model2img, model2model, img2text, img2img, img2model, text2text, text2img and even text2model [41, 42, 43]. Thus, it becomes clear that various currently most advanced approaches fall under the same category. These approaches include GAN algorithms [44], such as ArchiGAN by Stanislas Chaillou [45], which generates architectural floor plans from input shapes (Fig. 17), along with img2img section of generators like DALL-E [46], Midjourney [47], and Stable Diffusion [48].

Furthermore, by exploring the methodology followed by those approaches, it can be observed that they fundamentally involve certain common steps such as: Encoding, Decoding and Generation. The primary function of the encoder is to extract and encode the important information in a lower-dimensional form, enabling subsequent processing and generation steps. Consequently, reducing the dimensionality of 3D objects while preserving their essential characteristics often necessitates more intricate processing and analysis, requiring more computational resources and complexity compared to working with 2D objects. Therefore, as of the time of this thesis project, the advancement of 3D generative approaches lags behind compared to those in the 2D domain, with the most advanced approaches being Occupancy Networks [49, 50] and Neural Radiance Fields [51, 52], which are not suitable for use in this context.

Meanwhile, within the framework of architecture, it's fair to say that it consists of 3D forms, however, architectural drawings - plans, sections, elevations, and even axonometric and perspective drawings - are themselves 2D representations. Thus, it was concluded that it is currently more relevant to explore the potential of generative approaches focusing on 2D domain, with further elaboration within design platforms such as Grasshopper, attempting to perform "creative" transition between dimensions via abstract interpretation of values.

Abstract representation involves the creation of a simplified or stylized version of an object or concept that emphasizes its essential features and characteristics while omitting or reducing less important details. In the studies by Parker [53]; Parker and Johnson [54] the use of semi-autonomous algorithms is discussed, specifically the Scale-Invariant-Feature-Transform (SIFT) algorithm, in processing large datasets of architectural images to generate new design outputs. SIFT workflows involve identifying and abstracting key architectural characteristics into geometric compositions and assigning codified key points, which are then processed to produce dynamic vector-flow-fields that can be optimized for specific performance criteria. The authors recognize that SIFT algorithms rely on input images and generate "novelty" based on their relation to these inputs. Nevertheless, the paper highlights the value of SIFT algorithms as a tool for architects and designers to generate fresh design options and explore the potential of extensive architectural image datasets through autonomous interpretation of data (Fig. 18).

Nonetheless, there are several examples beyond architectural field, such as AlphaFold [55] and research by Y. Takagi and S. Nishimoto [56] that showcase potentiality of AI technologies in complex behavior prediction through state-of-the-art approaches based on scientific method [57]. And even warship design [58] not perfectly; however, with 100% accuracy, on over 400 complex tasks.

Figure 17: ArchiGAN
(Source: "NVIDIA" blog [45])

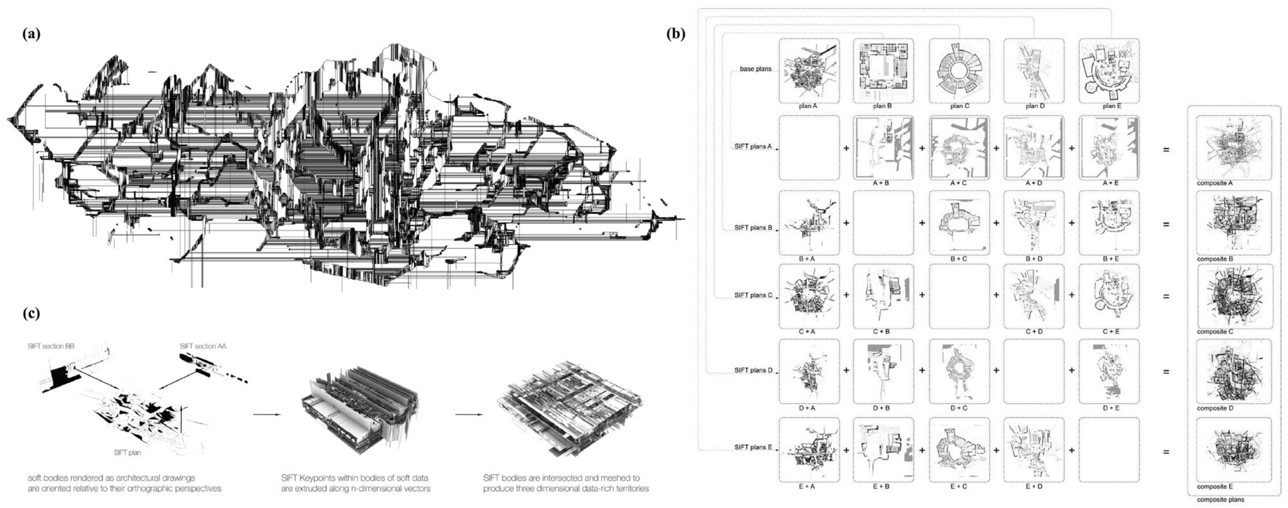


Figure 18: SIFT.
(a) Section Image created through SIFT' ing multiple project cross sections without biasing or postproduction; (b) composite image diagram. Composite plans created through the combination of various plan types found in the image data set.; (c) 2D to 3D workflow diagram for SIFT geometries

(Source: J.S. Johnson, M. Parker, 2016, p. 192,193,194 [54])

AI ART:CREATIVITY AND ETHICS

Considering the complex relationship of AI and Art (Fig. 19) and how much the subsequent material relies on the foundations and principles taken from the mentioned generative systems, it is worth clarifying a couple of technical points through simplified analogies for better understanding.

In broad terms, it can be said that the resulting outcome is the quintessence of connections, considering their optimal compatibility based on embedded data. This is a kind of chimera from the style and composition embedded in each individual image, and therefore emotions behind them. In fact, this means that it is not a collection of cold and soulless pixels, but rather a combination of qualities that correspond to the intention and meaning that the user wanted to embed in the result, chosen among the generated alternatives.

It is also important to review the counterargument that "they do not create anything new beyond their dataset," which is essentially true, but not in the sense that many people understand it. It refers to the creation of something fundamentally new that has no analogies and is not composed of simpler components already existing in the database. For example, a musically oriented approach is able to generate every possible combination by understanding what the notes are. Mostly chaotic, nonsensical, or lacking artistic merit, but, nonetheless, any. Therefore, this statement is equivalent to denying any idea as creative if it falls under these conditions, which is absurd. It is also important to understand that these models are 'probabilistic,' so at a structural level, everything generated is a new and unique result with a unique composition, even if it closely resembles a specific reference. Moreover, considering the fact that the "machine" contains examples (representations) of thousands of types and versions of objects, as well as different means to integrate additional knowledge, the question of limitations rather has the opposite effect.

Generally, performing complex tasks using an AI system that is not well understood by the human operator or is too complex for the operator to have complete control over the results can pose significant ethical problems, particularly in high-stakes situations where the potential for harm to individuals or society is substantial. For instance, when an AI system is employed to make medical diagnoses or recommendations for treatment, the existence of processes that may guarantee that the system does not make erroneous or harmful decisions, is crucial [60].

However, there is no necessity to completely avoid situations where the human operator is unable to grasp the AI system's intricacies or completely control its outputs. In the case of more abstract decisions, it is more important to ensure an adequate instead of complete level of understanding and control in order to obtain a more flexible tool.

As per Joi Ito [61]: Today, it is much more obvious that most of our problems cannot be solved simply with more resources and greater control. That is because they are the result of complex adaptive systems that are often the result of the tools used to solve problems in the past, such as endlessly increasing productivity and attempts to control things. This is where second-order cybernetics comes into play—the cybernetics of self-adaptive complex systems, where the observer is also part of the system itself (Fig. 20).

" Instead of thinking about machine intelligence in terms of humans vs. machines, we should consider the system that integrates humans and machines - not artificial intelligence, but extended intelligence. Instead of trying to control or design or even understand systems, it is more important to design systems that participate as responsible, aware, and robust elements of even more complex systems. Therefore, we must question and adapt our own purpose and sensibilities as designers AND components of the system for a much humbler approach: Humility over Control. Something we could call 'participant design' - design of systems as and by participants."

Figure 19: Symbol of AI Art boycott
(Source: "DevianArt" platform, created by JMK-Prime [59])

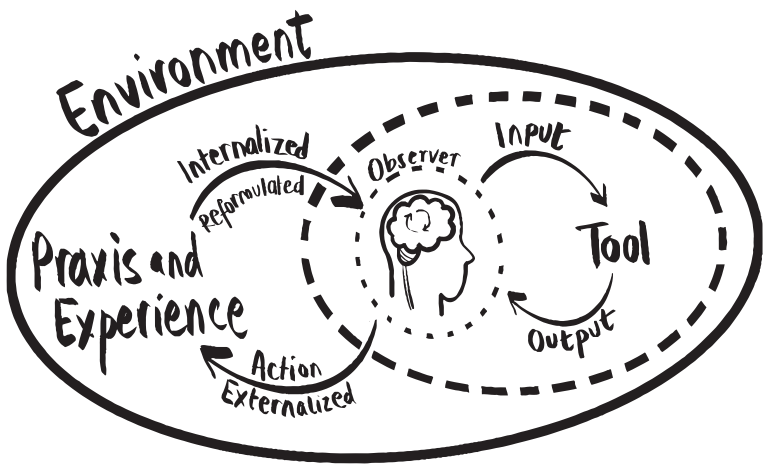


Figure 20: Second-order cybernetics adaption to psychological theory
(Source: S.Tilak et al., 2022,p. 18 [62])

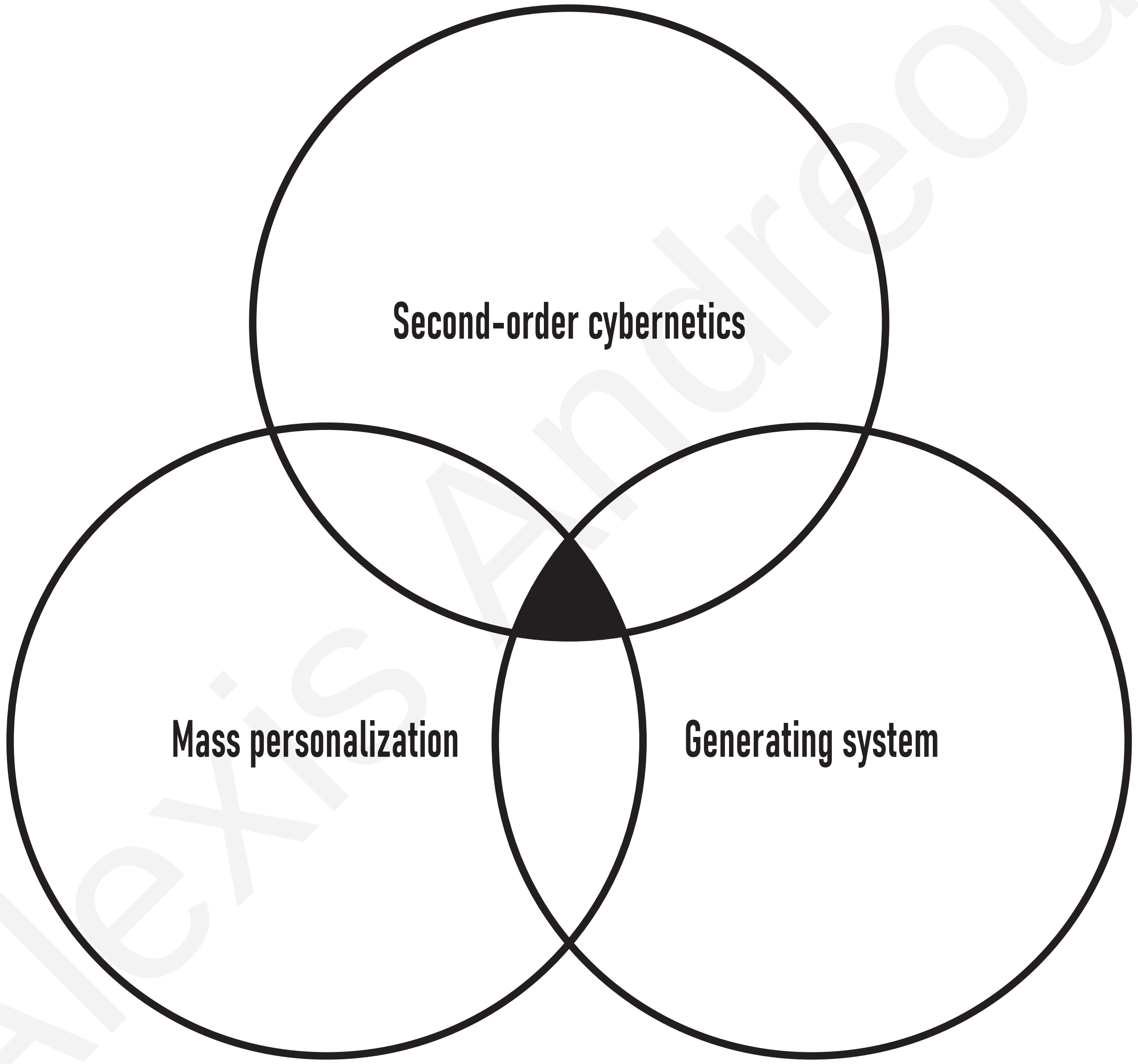
SUMMARY

Based on provided research and analysis, it has been observed that mass customization serves as enabling business and technological foundation for empowering and enriching social and cultural construct such as ‘design democratization’. Thus, considering previous experience and current technological capabilities, it is more feasible than ever to achieve approaches such as mass personalization, leading more individuals to actively participate in the design process, becoming co-designers instead of mere customers.

This shift towards increased involvement holds the potential to create more diverse and heterogeneous cities. It counters the trend of uniformity that characterized many cities in the twentieth century and continues to persist in numerous new urban and suburban environments worldwide. Embracing principles of difference and variety, rather than repetition, could lead to more vibrant urban landscapes.

To support this vision, a framework based on rule-based design systems can be employed. The three levels of customization—cosmetic (current norm), dimensional (next frontier), and topological (future)—should be considered within this framework. The framework that will contain all of the above variations will allow research-oriented designers to extrapolate specific and generic design systems from existing designs, achieving even greater customization, and alignment with user values.

DESIGN PROPOSAL


Second-order cybernetics
Mass personalization
Generating system

GENERAL PLACEMENT

The main idea of subsequent proposal originates from concepts such as mass personalization, generative systems and second – order cybernetics. In order to provide insights that would be difficult or impossible to obtain using traditional programming or manual creating techniques, it is proposed to construct a single flexible model capable of learning as type of knowledge transfer and design enhancement through informed and aligned generations. Therefore, the following principles were selected as necessary for its realization:

Holistic Multisystemic approach: Considering that architecture is a multifaceted and multidisciplinary field that binds different elements into a single system, something that requires a broad understanding of their relationships and compatibility, with corresponding approach. For example, in the natural process, elements on the larger scale change (climatic changes) and smaller parts of the system (man, animals) have to adapt. However, the nature and magnitude of these interactions can vary depending on the context and the specific elements of the system involved. In some cases, changes may be driven primarily by one scale or environment, while in other cases, changes may be driven by interactions and feedback between multiple scales or environments. Therefore, it is more accurate and useful to approach the study of environments and their interactions from a holistic and systemic perspective, considering how different components and scales are interconnected and influence each other, an approach that acknowledges the complexity and multi-faceted nature of environmental systems helps us to understand the interplay of different factors in shaping human behavior and outcomes.

Knowledge-based method with learning abilities: The use of a particular method is more rational due to the overwhelming number of parameters present in complex higher-order systems, making it difficult to manually manage all of them. Also, it may be significantly more valuable to slightly adapt the proposal in order to meet as many criteria as possible, especially considering the fact that most probably there is already a perfectly solved solution that is almost identical. Moreover, the possibility of enriching the system with new examples will provide a richer range of results with more relevant combinations.

Role reassignment: In order to meet the above principles, it is also necessary to review the current roles assignment. Thus, the role of the architect becomes obvious if we assume that the working model is built, and it produces relevant results. Because, after all, the obtained result is just a combination of "good" and even "best" scenarios of individual elements, which does not mean that every generation is appropriate, as noted earlier. Here is the point where the architect comes as a determining factor that selects which scenario serves a better conceptual requests and should be implemented.

For better understanding, the diagrams of simplified interpretation of those principles (Fig. 21-23) along with Comprehensive conceptual framework diagram (Fig. 24) are provided.

In fact, this is the role that architects currently fulfill. This understanding reveals the core essence of the entire concept, which aims not to alter the fundamental nature of architecture, but rather to enhance and optimize design processes achieving greater efficiency and alignment with user input, thereby elevating the overall quality of design outcomes. In other words, this concept aims to expand the entire profession boundaries instead of just personal, by developing a system capable of managing routine tasks, allowing architects to focus on complex synthetic problem solving. However, it is important to acknowledge that this approach is not a universal solution to all problems, but rather an approach that values negative feedback and diverse perspectives as necessary components for continuous improvement over time.

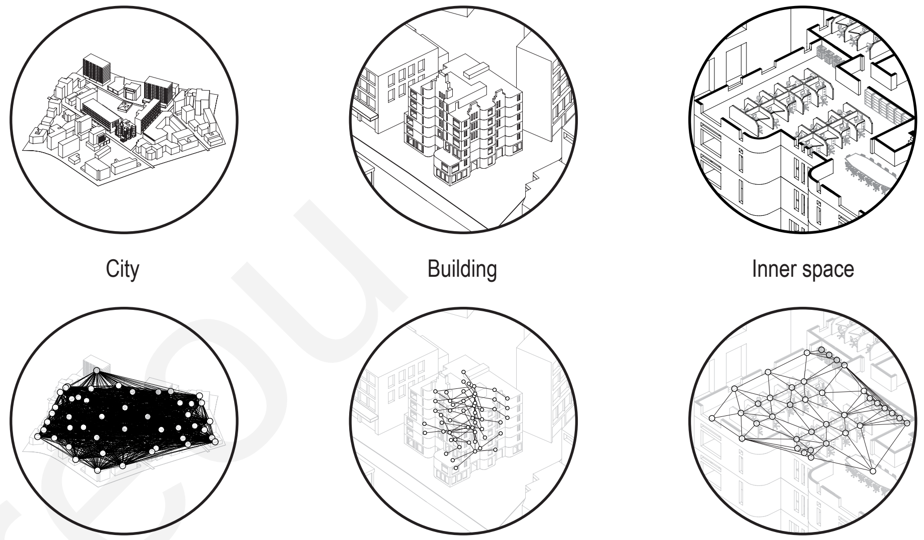


Figure 21: Multiscale interpretation of relationships

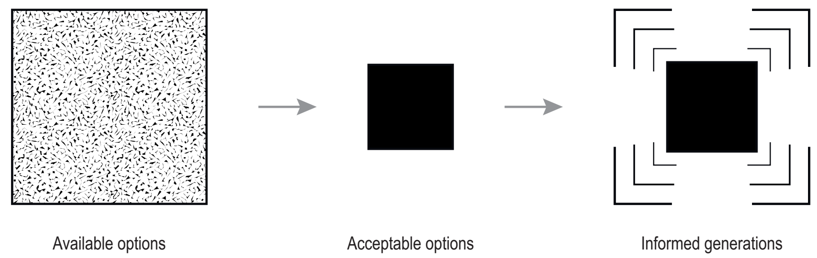


Figure 22: Conceptual model

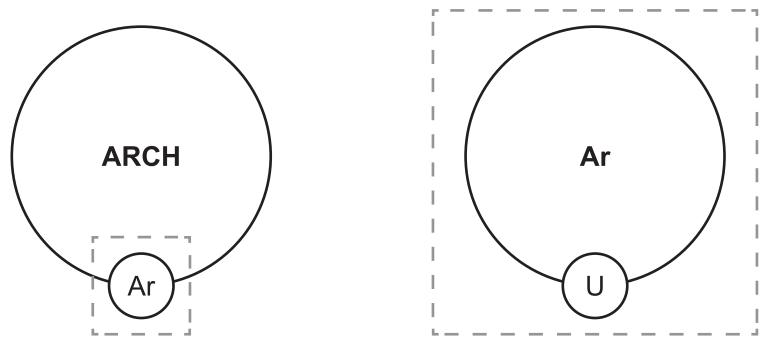


Figure 23: Multiscale perception of roles

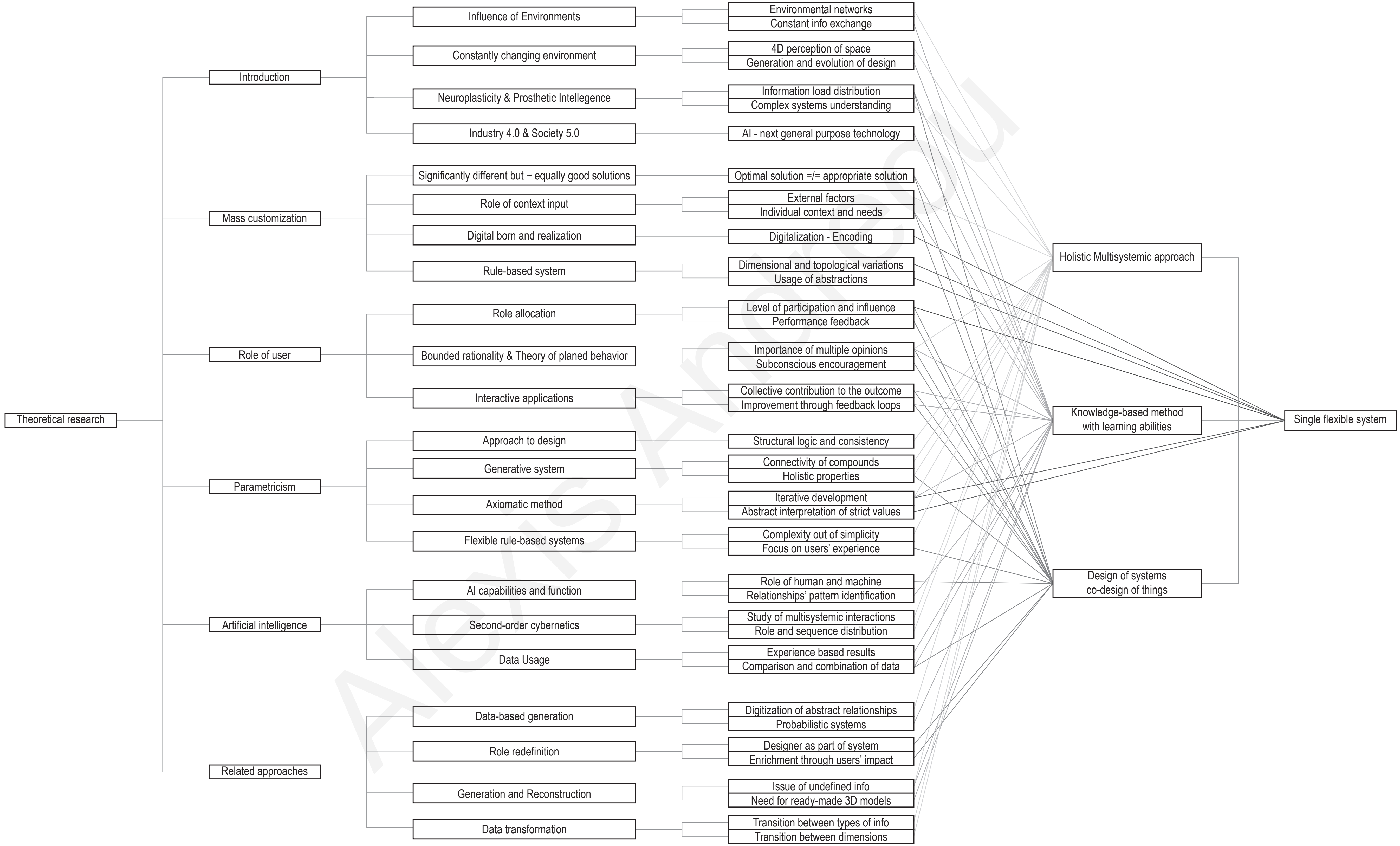


Figure 24: Comprehensive conceptual framework

ADDITIONAL CONDITIONS

Despite the optimistic predictions, developing a comprehensive version of this model necessitates significant investments in time, computational power, and storage space due to the continuous need for expansion. Meanwhile, according to the research, any holistic system requires a precise depiction of its intended behavior, the interactions among its relevant components, and the mechanisms that facilitate these interactions. Hence, obtaining a complete understanding is crucial before presenting fragmented aspects of it.

Nevertheless, based on studied principles besides the ML processing part, the most important part is to establish a process for input data 'encoding' with further ability for reuse. That is also a highly complex and multifaceted task that demands a substantial number of ready-made tools and/or the creation of new ones, which in their complexity may not fall short of the concept itself.

Considering all the aforementioned factors and the available tools, this work proposes a model that adheres to the original principles but in a limited form (Fig. 25-27). For instance:

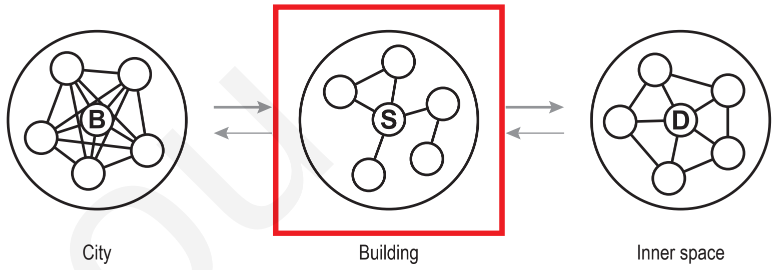


Figure 25: Focusing scale

1) **Focus on building scale**

While the overall process can be divided into three main scales, it is important to note that the transition from the urban scale to the building scale primarily involves complex processing of solid data, which is mostly a technical aspect that has been remarkably examined within research by X. Zhuang et al. [63]. On the other hand, the exploration of the inner space scale has already been pursued through various approaches and requires a large dataset of assets. Meanwhile, the scale of the building, a more delicate approach is required as it serves as the connective link between these scales.

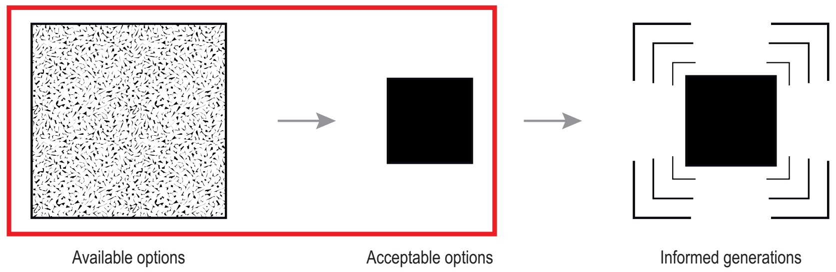


Figure 26: Encoding of options

2) **Not a complete system but design method as tool for its development**

Meanwhile, the methodology followed by computer vision approaches involves steps such as: Encoding, Decoding and Generation. In this case, it is proposed to use numerical inputs as a form of encoding, providing the necessary information for the generative algorithm to produce the desired output. The generative parts of algorithm directly utilize these numerical inputs without the need for an additional encoding or decoding step for easier compatibility with potential ML computing part.

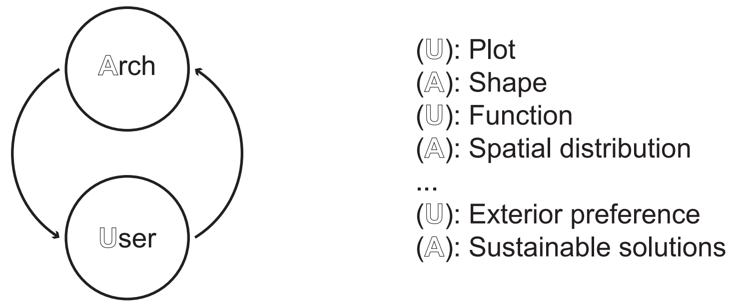


Figure 27: Example of participation freedom

3) **Limited freedom of choice due to requirement of a complete trained system**

As mentioned earlier, in order to provide high ability of customization, a complete model is required. Therefore, the involvement of the user is limited to a selection among variations based on produced values, meaning that all of them may be considered as appropriate in terms of quality.

METHODOLOGY

As mentioned earlier, due to technical limitations caused by buildings' topological complexity and variability, none of the computer vision methods can be fully implemented. Therefore, it is necessary to develop a new approach which is capable of meeting all the mentioned conventions.

As an alternative, the method of using minimal abstraction (words and numbers) as input data is proposed. The support of both types of information is necessary since in architectural design, apart from purely empirical values, there are also more abstract forms of information, with text being the minimal abstraction of such information.

Next, based on the idea that any design exists and can be expressed by a certain sequence of actions, it is proposed to use step by step transition between dimensions keeping their connectivity in order to inform each particular component if required, no matter of its dimensionality.

Then, to provide variability, each stage of dimensionality change presupposes options for further development as a way of customization. See full diagram (Fig. 28)

Additionally, to demonstrate the capability of generating variability, it was decided to employ an existing building as a source of values and a benchmark for subsequent comparisons. Thus, the "AT&T" building designed by Phillip Johnson [64] was selected as the reference building (Fig. 29).

Summing up, all the aforementioned elements can be illustrated within the pipeline process (Fig. 30) that can be broadly categorized within 3 main parts: Model creation, Revisualization and Performance evaluation. The context forms the domain of the building, while the architect provides spatial division that not only shapes the 2D space but also the entire shape. After that, it is required to use external platforms based on DL techniques such as "Stable Diffusion" and "PSPNet" [65] in order to provide and prepare the characteristics of desired choice for subsequent use in partial LCA evaluation (annual energy efficiency and carbon emission). It is worth noting that the information obtained through image digitization serves as a valuable resource not only for exterior generation but also as input data for inner space formation (3rd scale), as it encompasses the composition along with each material ratio and distribution.

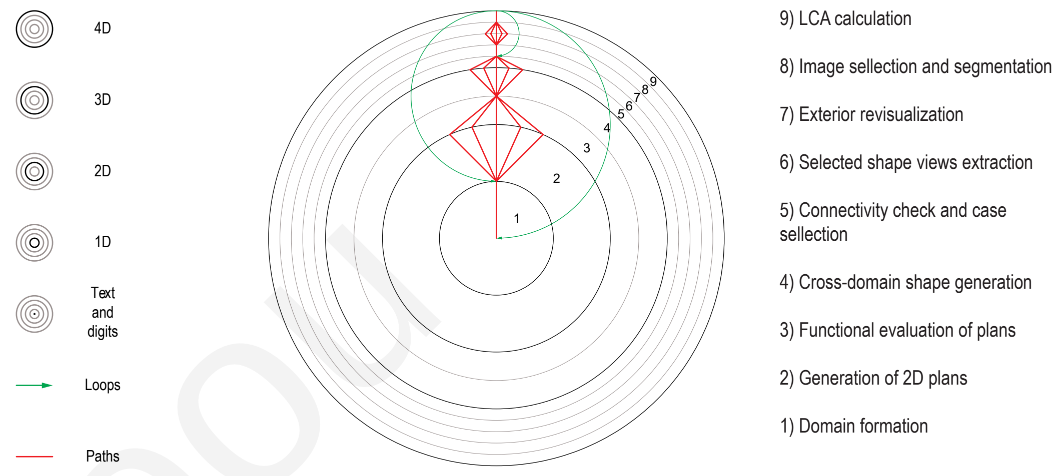


Figure 28: Methodology workflow

Figure 29: AT&T Building
(Source: "The Architectural Review" magazine [64])

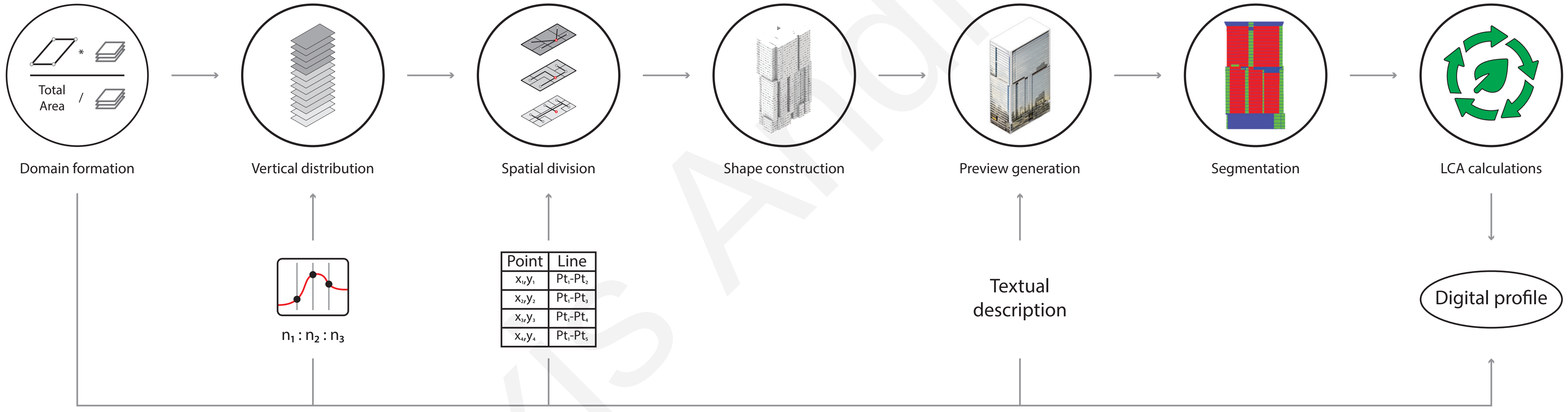
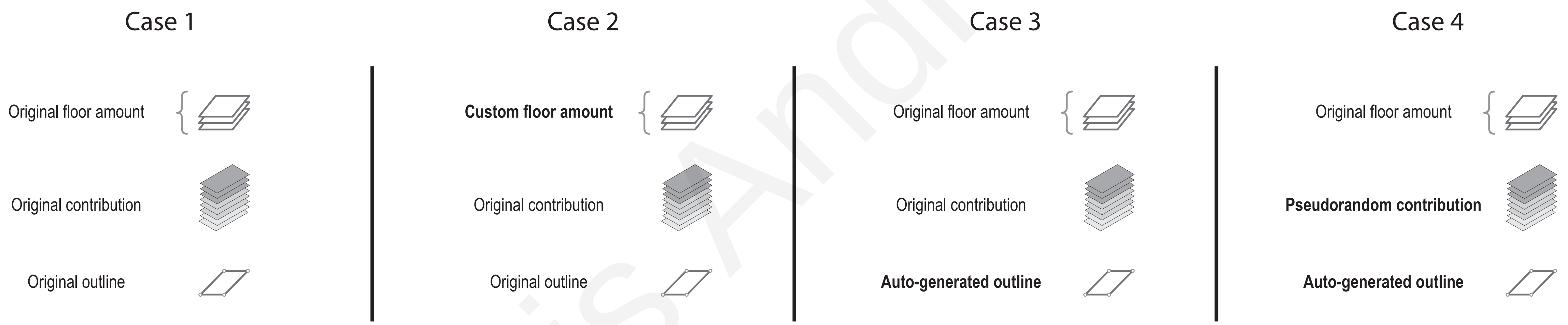
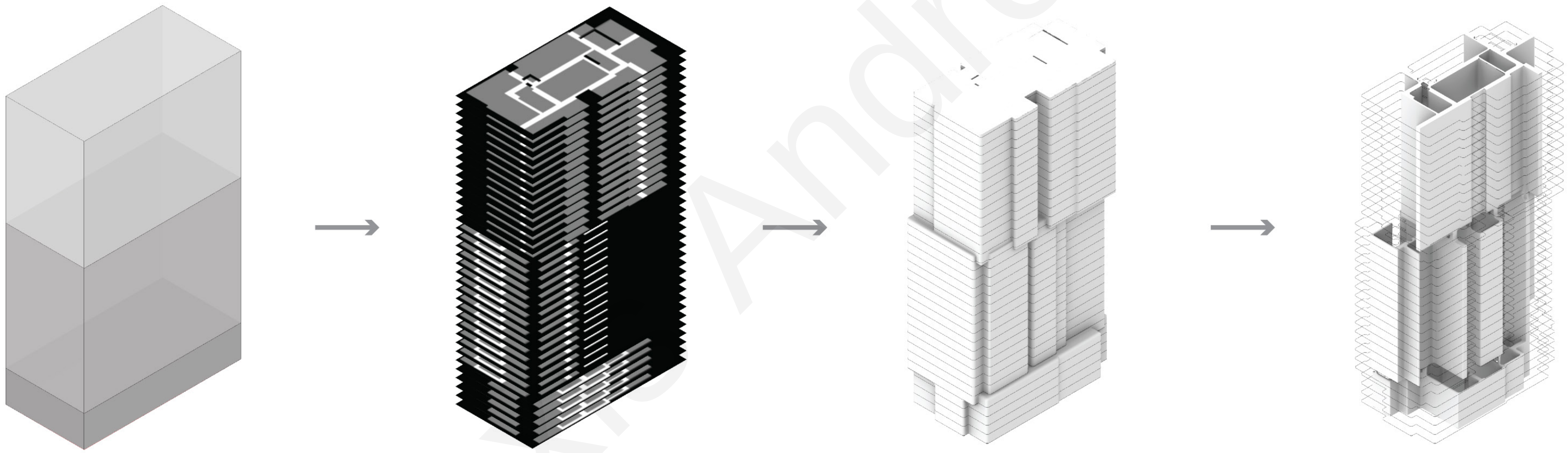


Figure 30: Pipeline process diagram

RESULTS


Case 1
Original floor amount
Original contribution
Original outline
Case 2
Custom floor amount
Original contribution
Original outline
Case 3
Original floor amount
Original contribution
Auto-generated outline
Case 4
Original floor amount
Pseudorandom contribution
Auto-generated outline

MODEL CREATION



MODEL CREATION

The process of model creation takes place within the Grasshopper environment [66] of Rhinoceros software [67] and consists of the following parts:

- Domain formation
- Spatial division
- Shape construction

To begin with, as mentioned earlier, due to a range of constraints, the input of context is excluded within the proposed workflow except the plot; hence, the number of inputs is limited and all of them are being handed manually. The inputs are:

- Specific outline (curve) OR total area (number)
- Number of floors
- Floor height

The second part involves 2D plans generation and extraction (as images). It is happening through "Magnetizing Floor Plan Generator" (MFPG) plug-in [68] with follow inputs:

- Manual space relationship diagram (Fig. 31)
- Entrance point
- Max distance between rooms
- Resolution of voxels

In the concluding phase, the generation of the 3D shape is achieved by the use of "Monolith" plug-in [69] in accordance with the selected options of each type in manually determined proportions.The complete algorithm can be observed in Fig. 32.

The process of image extraction is facilitated through the "Human" plug-in [70]. Meanwhile the generated results obtained from the initial processing stages which are being used for the subsequent stages are illustrated in Fig. 33-34 for spatial division and Fig. 35-38 for shape creation.

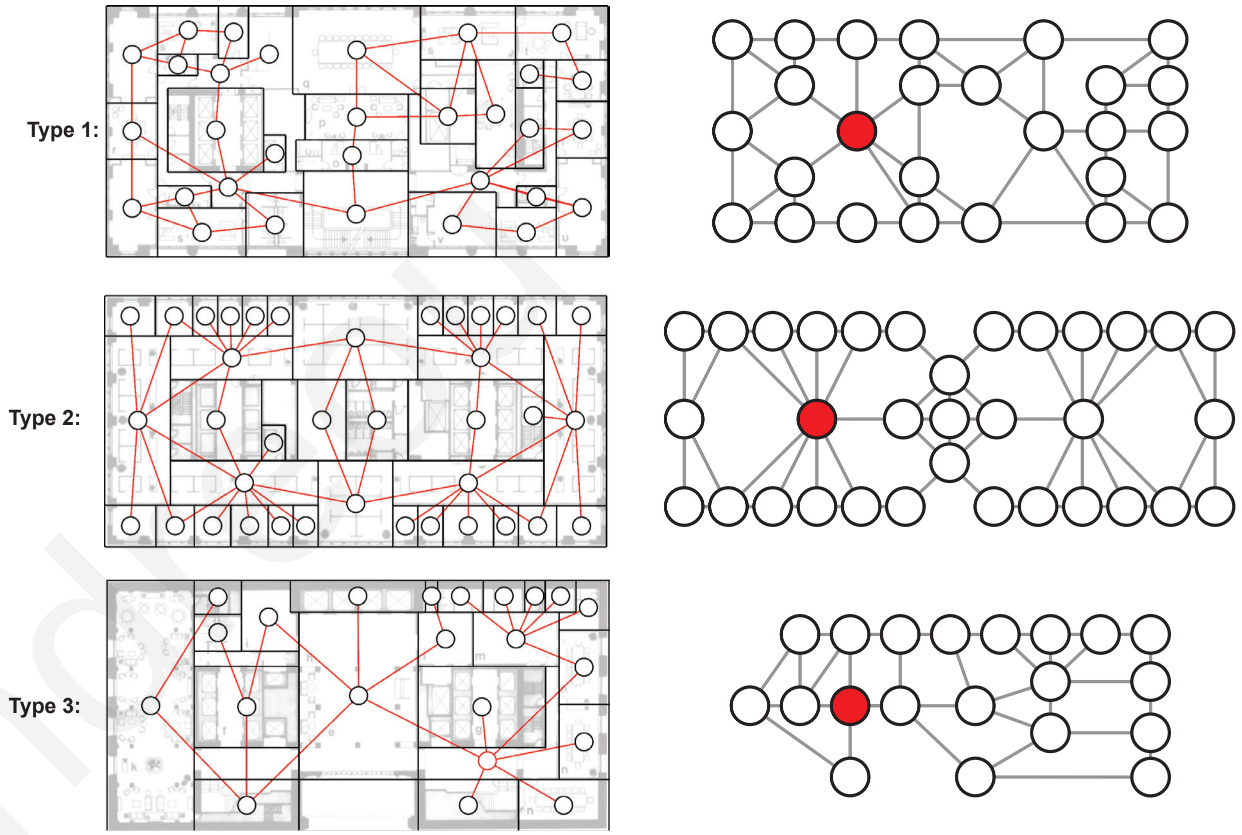


Figure 31: Relationship examination and adaption

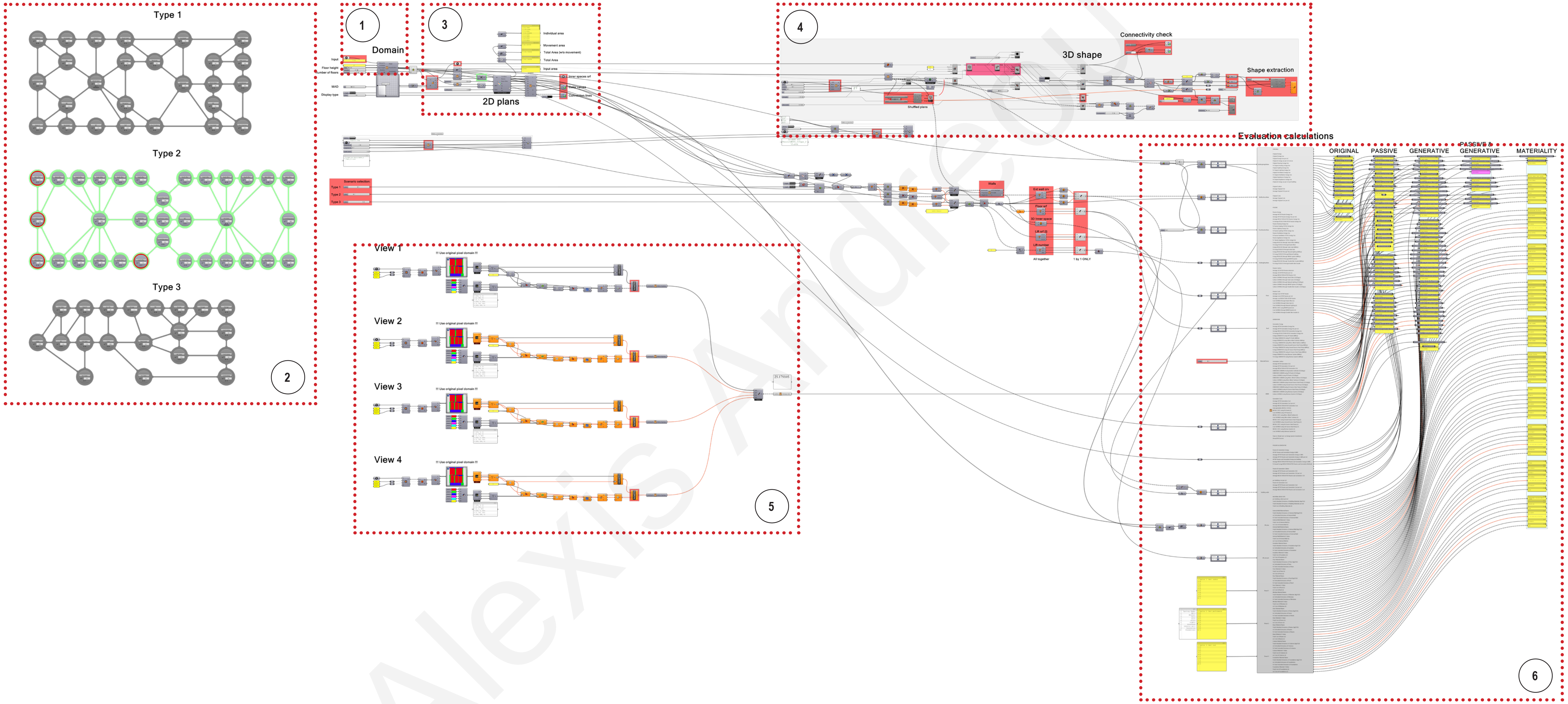


Figure 32: Full algorithm
(1) Domain generation; (2) Space diagram; (3) Plans generation;
(4) Shape creation; (5) Image digitization; (6) Performance calculations

SPATIAL DIVISION

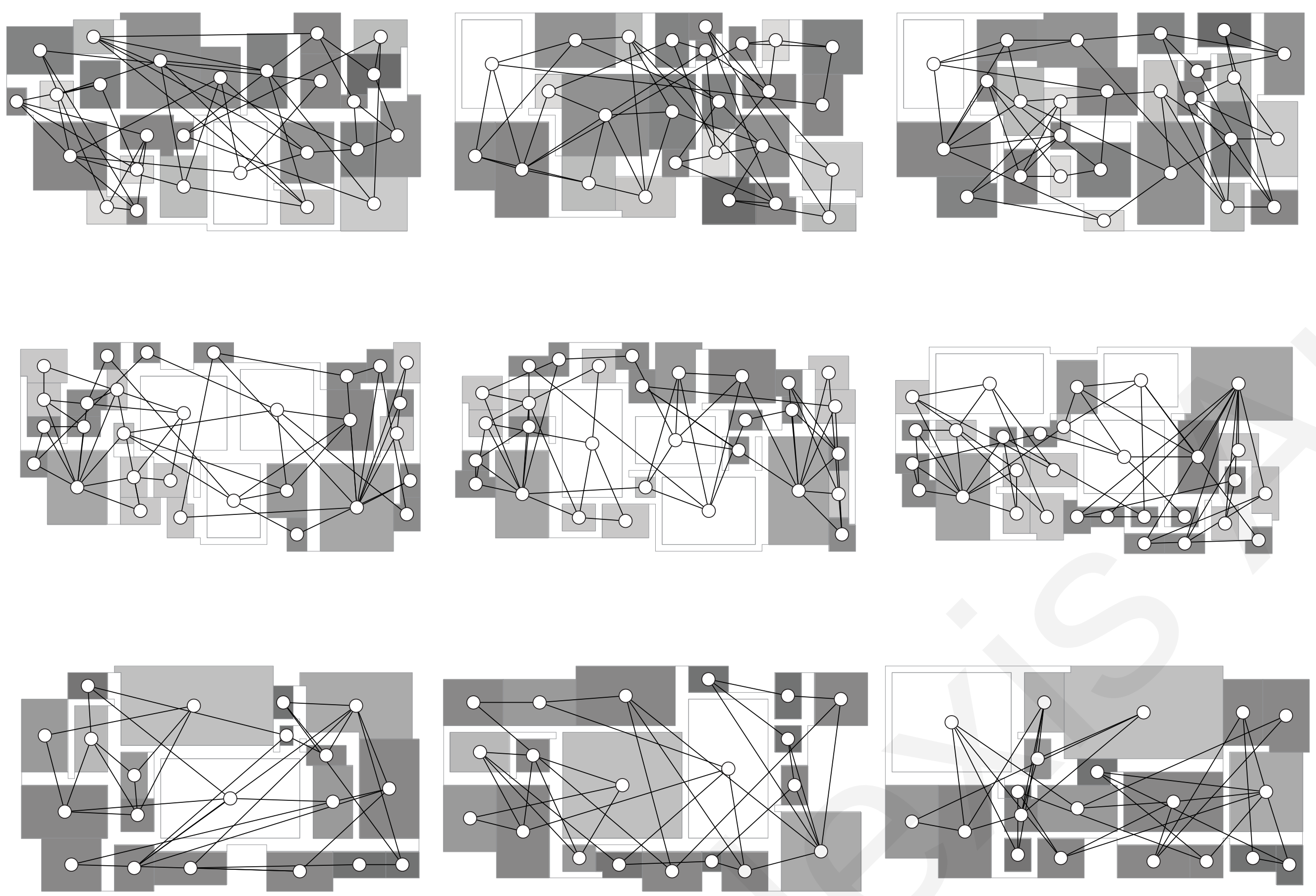


Figure 33: Spatial division case 1-2

Type 1

Type 2

Type 3

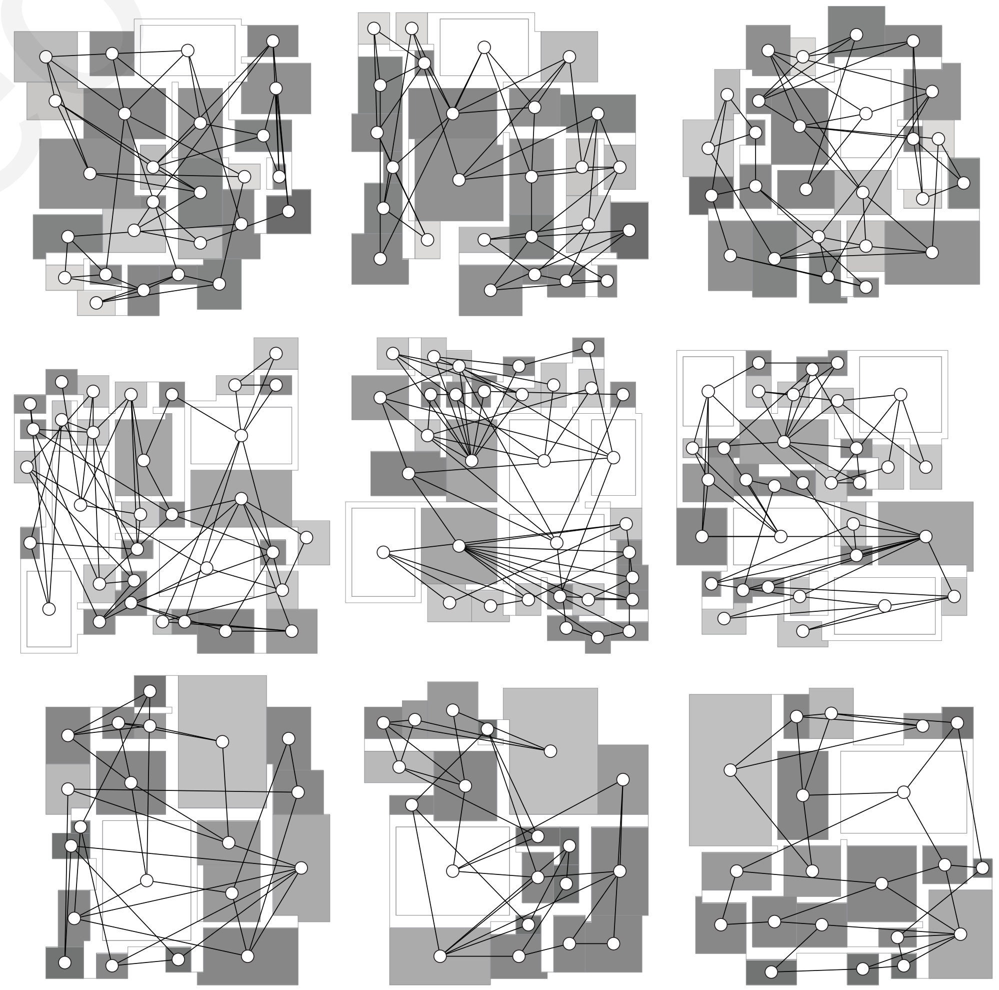


Figure 34: Spatial division case 3-4

SHAPE FORMATION

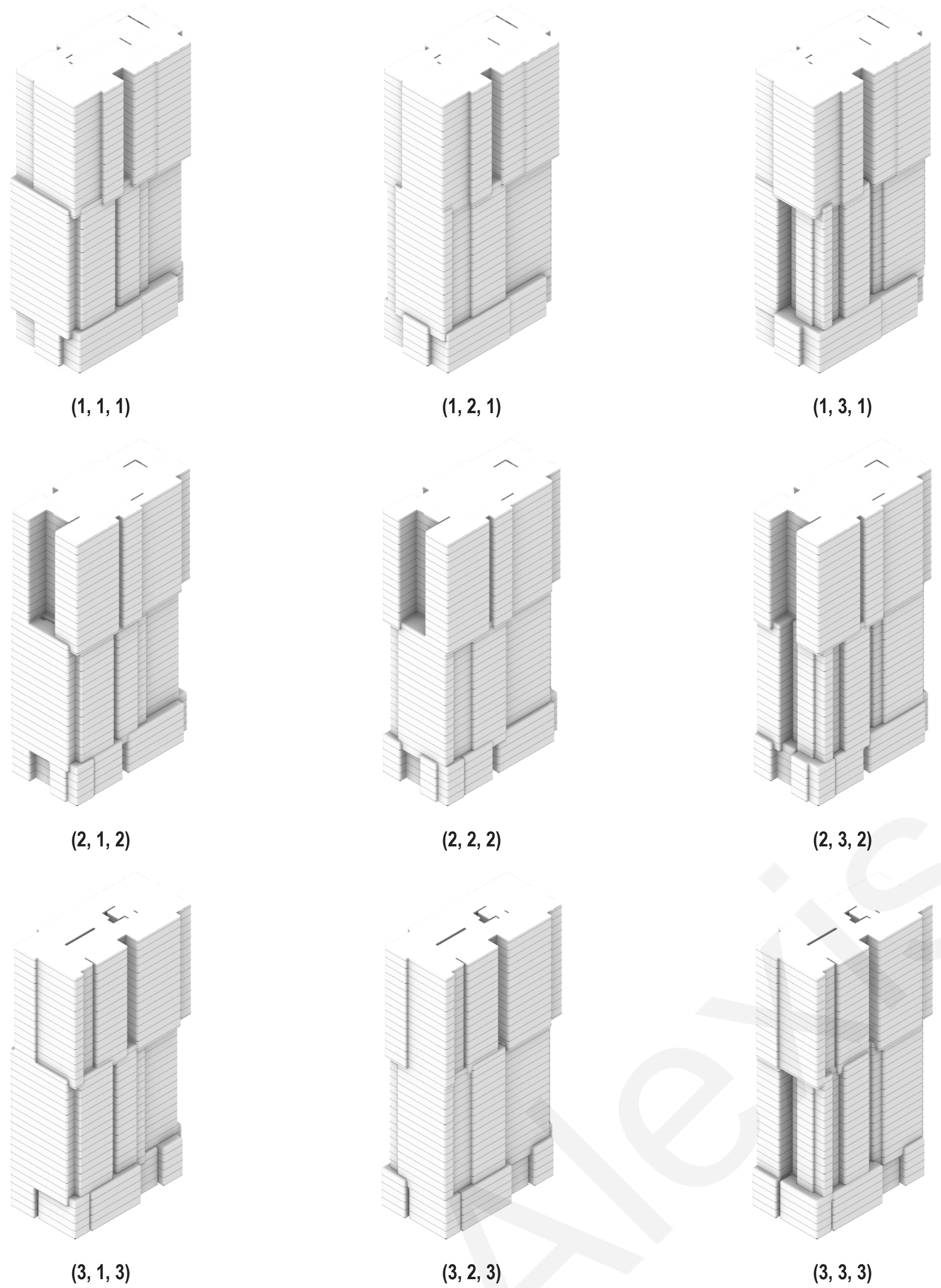


Figure 35: Case 1 shape variability

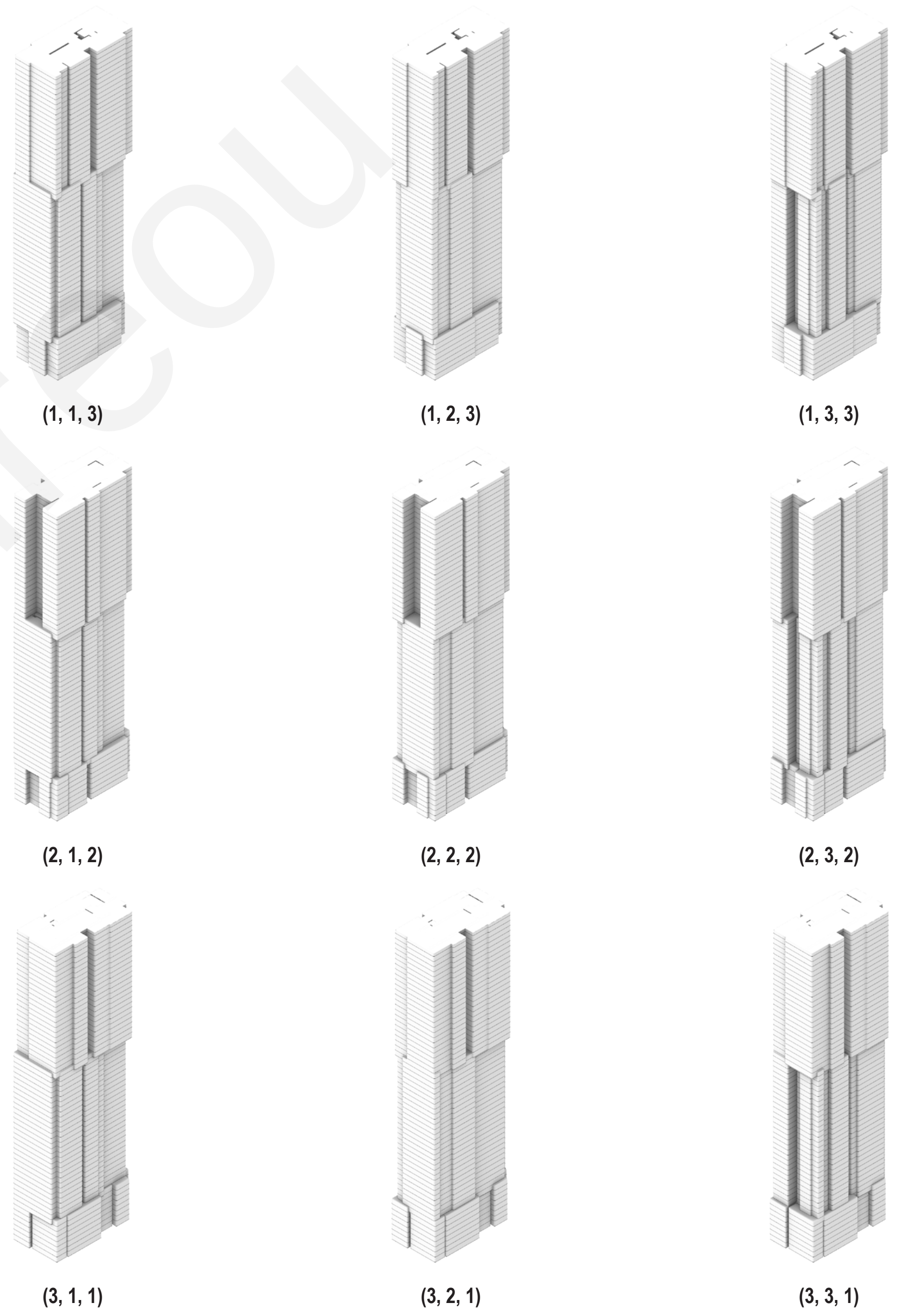


Figure 36: Case 2 shape variability

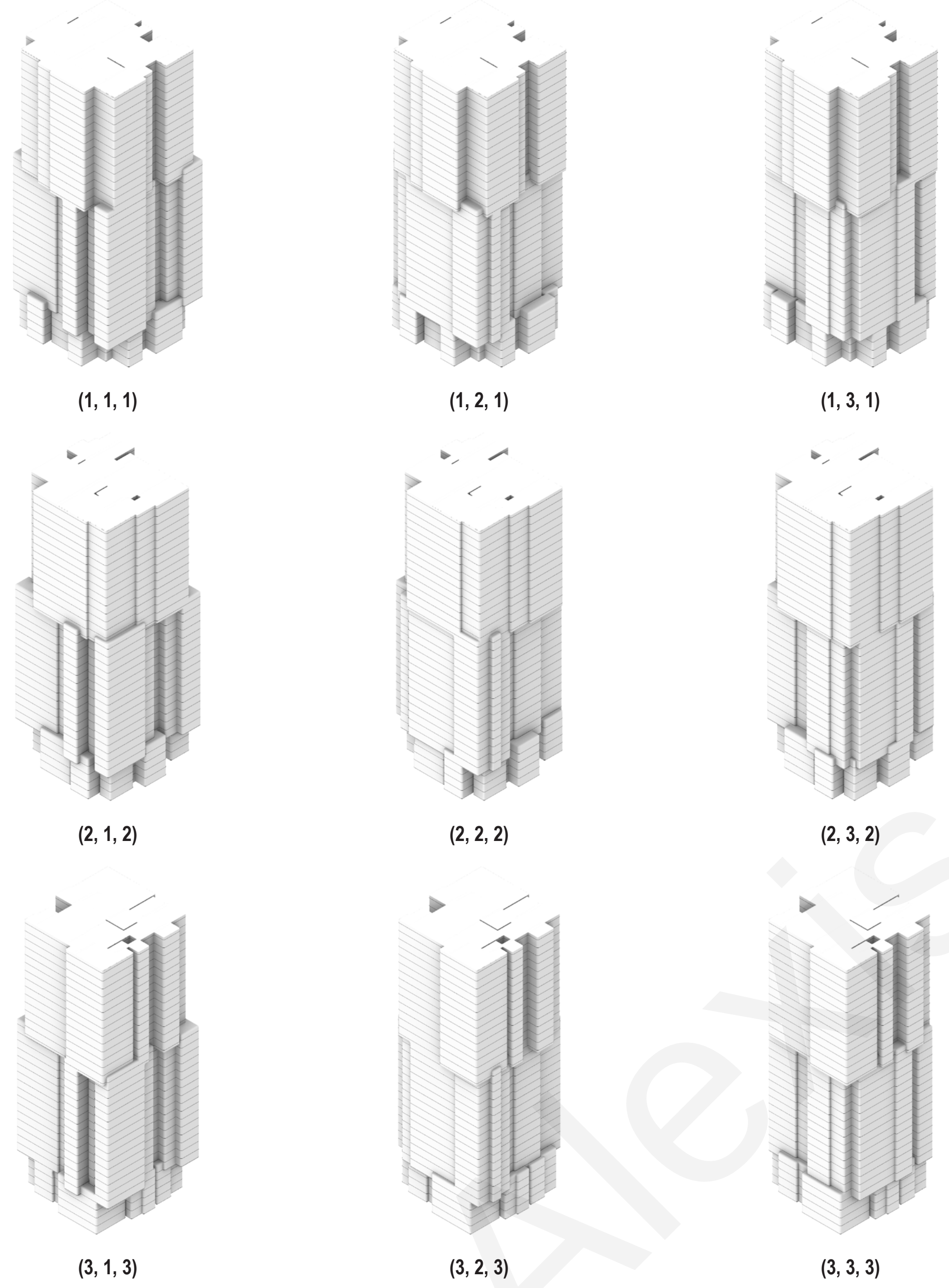


Figure 37: Case 3 shape variability

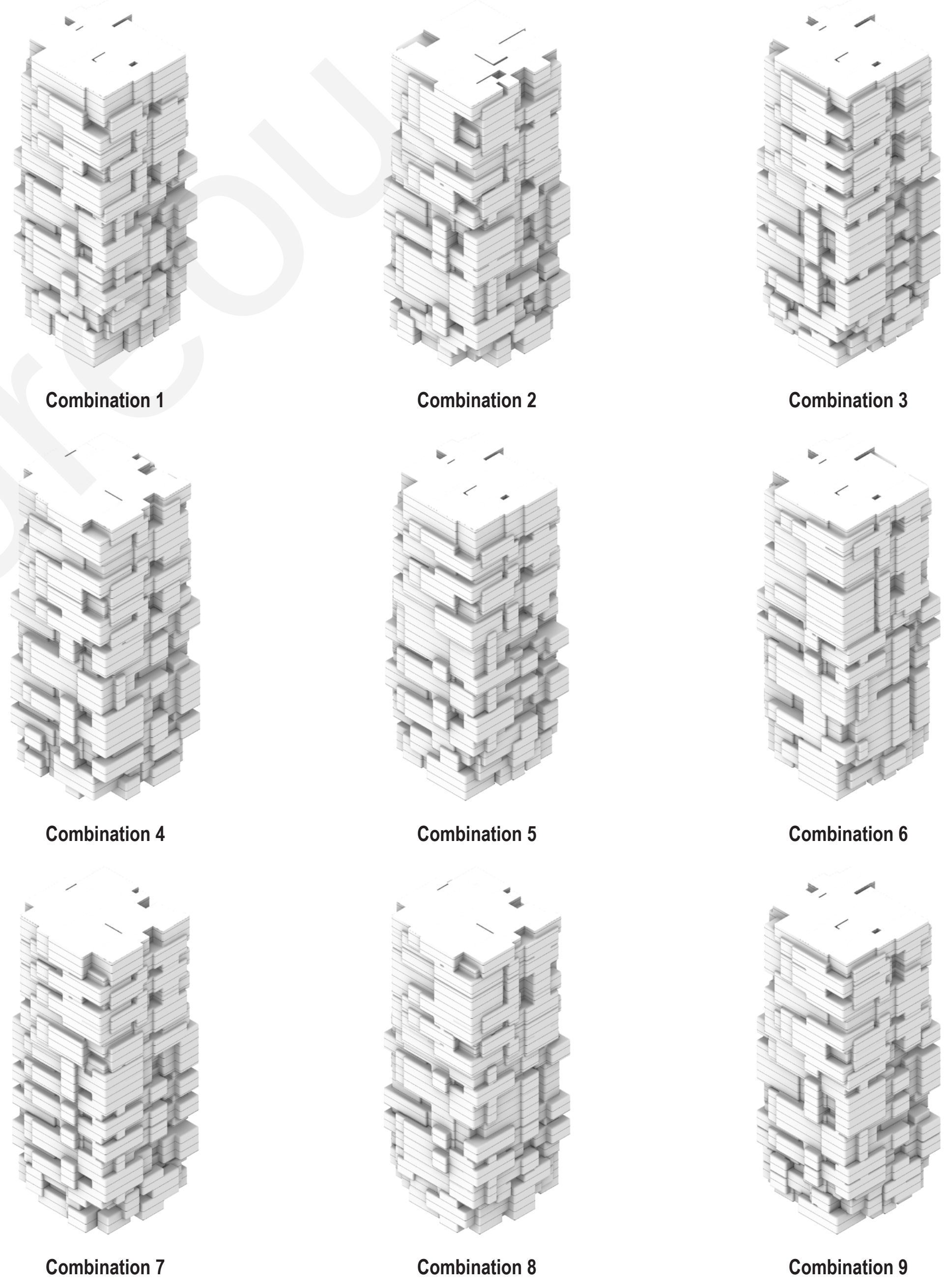
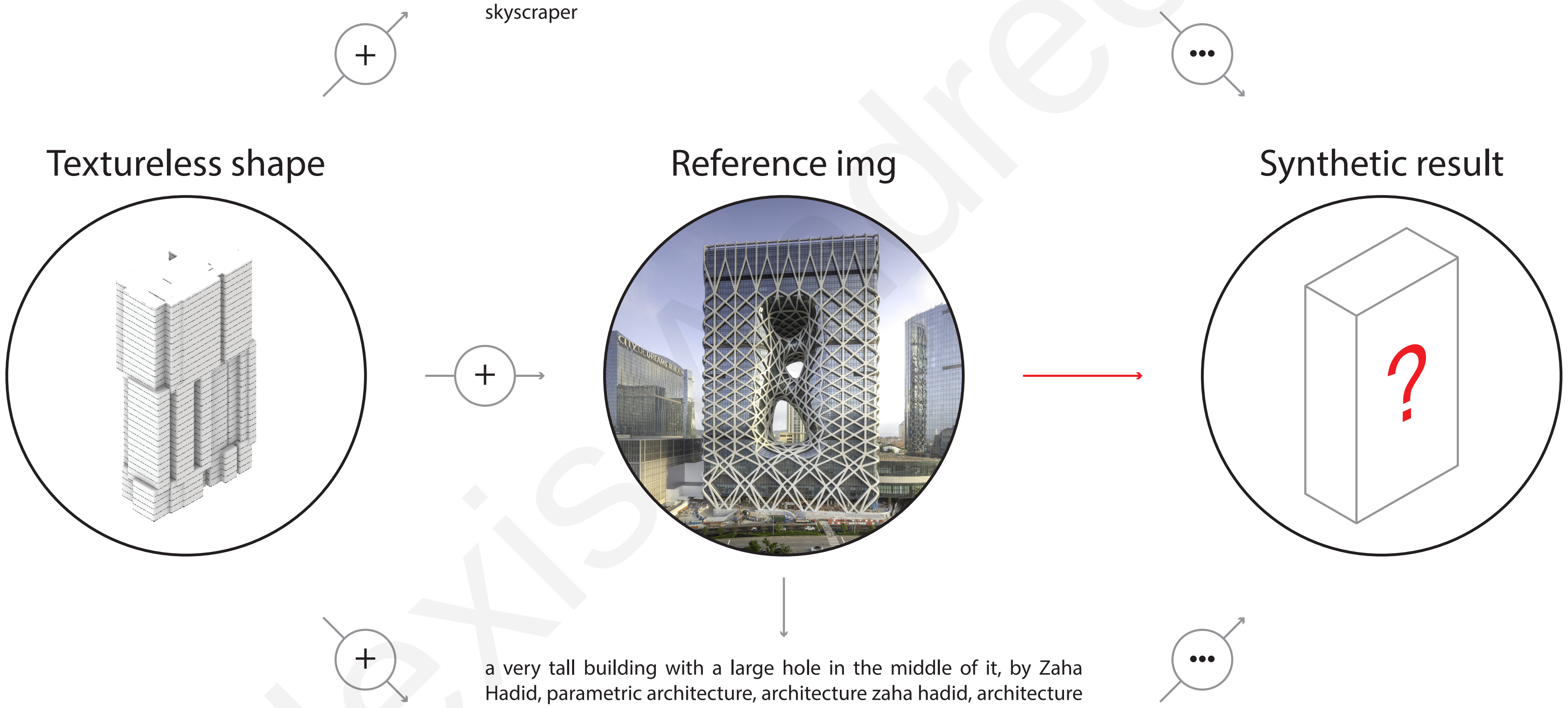


Figure 38: Case 4 shape variability

REVISUALIZATION

a very tall building with a lot of windows, futuristic, pritzker architecture prize, by Ricardo Bofill, avenida paulista, dezeen, renzo piano, transparent building, herzog de meuron, overwatch building, são paulo, tall building, capital plaza, big poor building, the building is a skyscraper



a very tall building with a large hole in the middle of it, by Zaha Hadid, parametric architecture, architecture zaha hadid, architecture digest, curvilinear architecture, zaha hadid building, zaha hadid style architecture, inspired by Victor Enrich, parametric design, zaha hadid architecture, bold architecture, maximalist sculpted design, sustainable architecture, portal. zaha hadid

REVISUALIZATION

The process of revisualization is performed via the portable version of Stable Diffusion (aka. web UI [71]) within the “img2img/Batch” tab. Fundamentally, the process involves the input of images and usage of a particular “model” along with a set of inputs such as:

- Prompt
- Negative prompt (optional)
- Resolution (Width*Height)
- CFG Scale
- Denoising Strength

In our case, the model used for this approach is called “512-depth-ema” [72] meaning that essentially the process is not img2img but depth2img. Additionally, an extension “stable-diffusion-webui-depthmap-script” [73] is used as an extra composition “preserve” component, also capable of exporting images with transparent background (a significant factor for further processing in Grasshopper).

Meanwhile, the key inputs required to provide guidance for generations are “prompt” and “negative prompt”. In simpler terms, these inputs indicate what we desire or do not desire to be included in the generated output. Nevertheless, it is important to acknowledge that not everything included in the prompt will be generated as expected or may not be generated at all due to limited data availability in the database. Furthermore, the quality of the prompt itself is crucial, as it adheres to specific structural rules and incorporates various symbols that serve distinct purposes. Hence, there are several ways to create it: manual, copying, generation by description, generation from reference image; within this project only ‘manual’ and ‘generation from reference’ have been used.

To proceed, the following scenarios were selected within the 4 cases:

Case 1: Scenario 1 (1, 1, 1)

Case 2: Scenario 6 (2, 3, 2)

Case 3: Scenario 4 (2, 1, 2)

Case 4: Scenario 7

Although some of the shapes have a complex typology to operate on, in order to explore the boundaries of the generative algorithm, it was decided to use the most complex side view of each case and referential description of a complex building. Specifically, the “right” view was selected as input image (Fig. 39), while “Morpheus Hotel” of ZHA [74] was selected as a referential building (Fig. 40). Results can be observed in Fig. 42-45.

Summing up, the creation of high-quality and intricate images necessitates meticulous effort and skillful prompting. However, generating coherent images presents a purely technical challenge without definitive solutions in the current stage of development. Therefore, the img2depth approach and a simplified prompt are used as the most effective way to achieve the appropriate coherence (See Fig. 46-49).

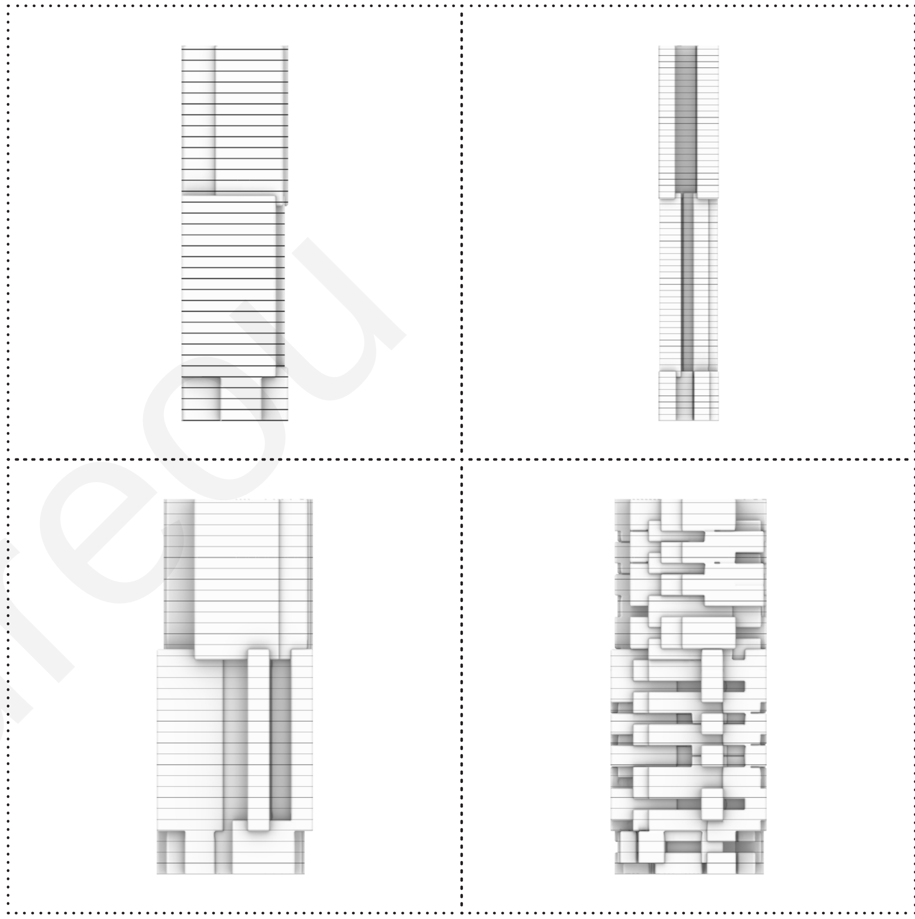


Figure 39: Selected views

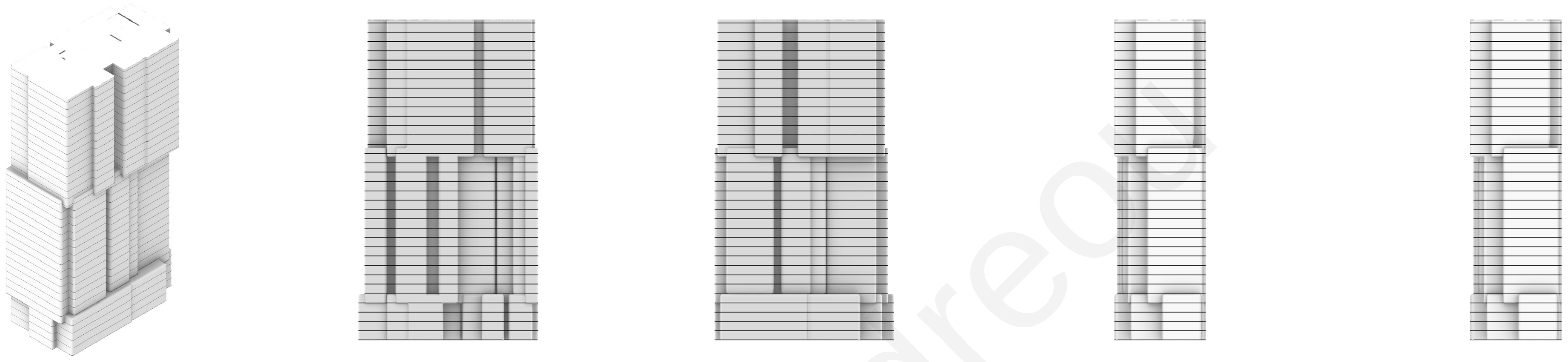
Figure 40: Referencial building
(Source: “ArchDaily” weblog [74])

Figure 41: Revisualization 1

Figure 42: Revisualization 2

Figure 43: Revisualization 3

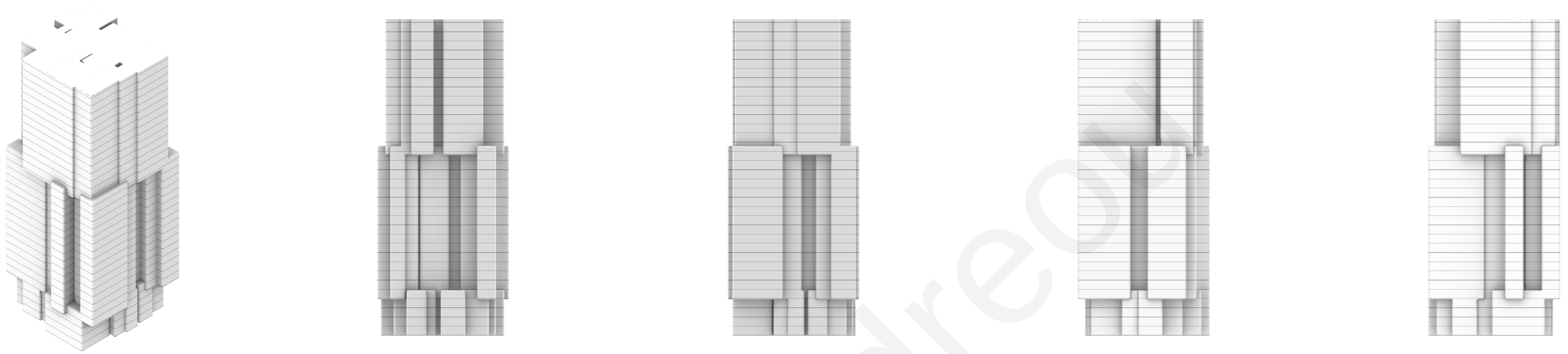
Figure 44: Revisualization 4



Perspective view | Front view | Back view | Left View | Right view

Figure 45: Revisualization 5

Figure 46: Revisualization 6



Perspective view | Front view | Back view | Left View | Right view

Figure 47: Revisualization 7

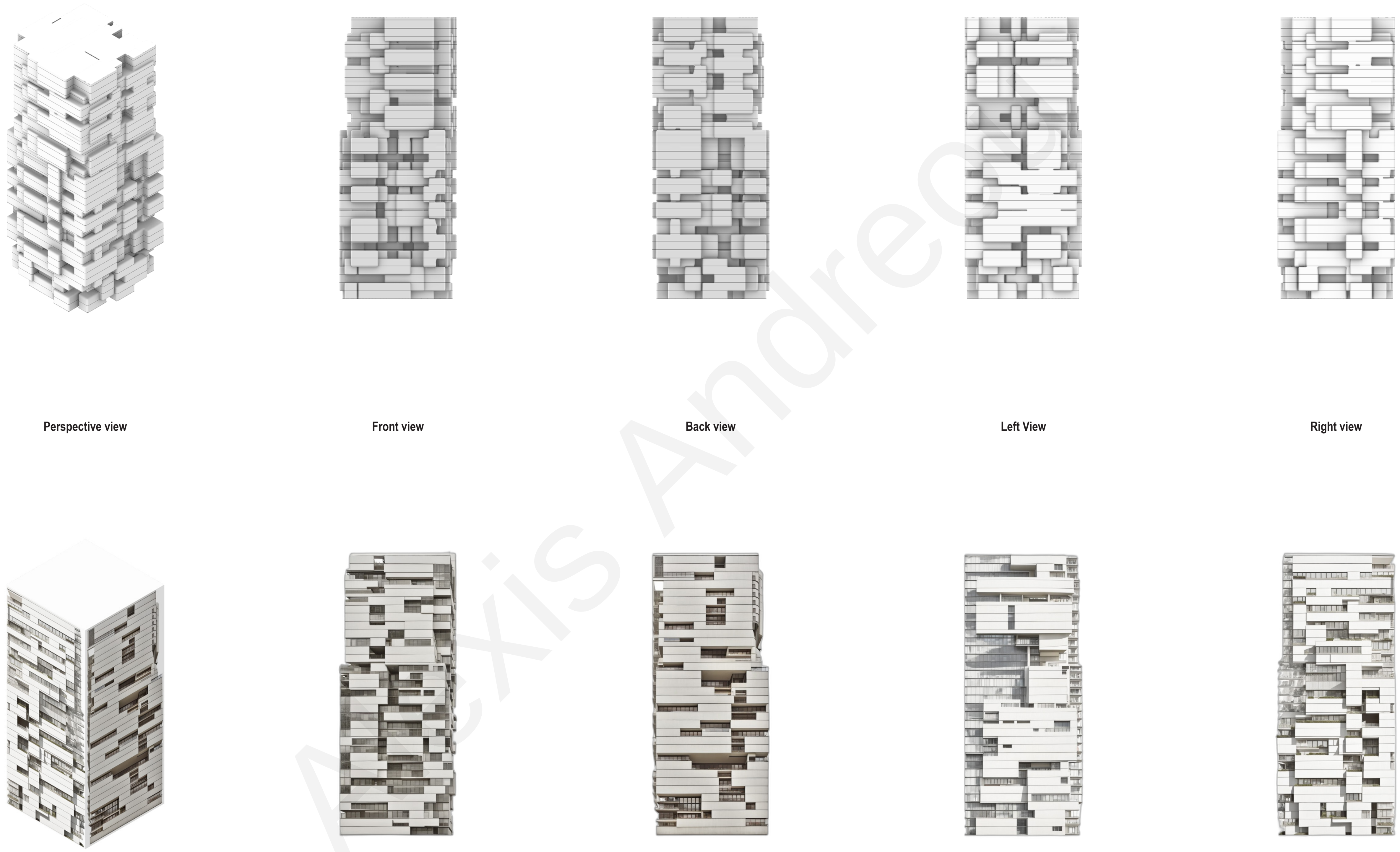


Figure 48: Revisualization 8

PERFORMANCE EVALUATION

Finally, the process of performance evaluation consists of the following parts:

- Image segmentation
- Value extraction
- Evaluation calculations

The further use of gained images requires their digitization through some image segmentation technique, which is a manageable task for models such as PSPNet (Fig. 49) as mentioned previously. However, this is a complex, time-consuming task requiring some technical knowledge in the field. Therefore, this part will not be featured in the proposed process, images edited in Photoshop are used instead (Fig. 50).

After that, the processed images are used as input in Grasshopper color sorting algorithm. The algorithm essentially consists of 2 parts, where the first one is the reconstruction of vertices {R, G, B} values into points {x, y, z} in 3D space and the second one is their division into groups (on the basis of the nearest absolute color value) using combination of “3D Voronoi” and “Point in Brep” components. It is important to note that the algorithm is based on absolute RGB values of colors (Red(R) – 255,0,0; Green(G) – 0,255,0; Blue(B) – 0,0,255; Magenta(M) – 255,0,255; Cyan(C) – 0,255,255; Yellow(Y) – 255,255,0), which means that the number of individual groups is limited to 6. In our case, only RGB are used, where: R - Solid Wall, G - glazing, B - anything else that is neither one nor the other.

The final aspect of the proposed design process includes an evaluation of generated results through a performance analysis that calculates both embodied carbon and operational energy needs for the design. This is achieved through the use of a grasshopper script developed as part of a master’s thesis by the CPU Atelier of Manchester School of Architecture. It incorporates both an embodied carbon and energy performance building material database that the final output draws from to analyse its environmental impact as well as potential energy generation capability if it incorporated solar panels. This enables more informed choices by the designer/user that include a sustainability dimension geared at reducing the negative impact of the building on the environment.

While the provided algorithm offers a broad range of performance metrics, this study focuses primarily on specific parameters such as:

- Original energy use & Average AFTER passive energy use
- Average original CO2 & Total embodied emission of building materials (kg/CO2)
- Average Original Cost & Total cost of building materials

Comparison based on generated and gained data can be observed on Fig. 51 where the main material choice was ‘Steel’ due to the height of the building with a WWR - 25, based on the extracted values of the generated image.

Figure 49: Example of segmentation
(Source: H. Zhao et al., 2017, p. 7 [65])

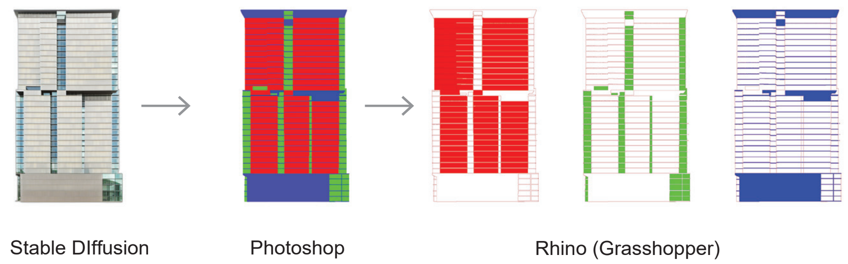


Figure 50: Digitization process

	Type 1				Type 2				Type 3			
	Original	Case 1	Case 2	Case 3	Original	Case 1	Case 2	Case 3	Original	Case 1	Case 2	Case 3
Original energy use	6911.01	13330.8	6760.98	6324.69	6492.90	5634.35	5720.52	5685.21	7324.01	14302.03	7316.90	7219.99
Average AFTER Passive energy use	4668.06	7654.64	4742.92	4667.56	4554.78	4503.92	4533.73	4566.14	4943.14	8209.96	4983.30	5008.35
Average original CO2	6496.35	12530.96	6355.32	5945.20	6103.33	5296.29	5377.29		6884.57	13443.91	6877.89	6786.79
Total embodied emission of building materials (kg/CO2)	9.0866e+7	1.0689e+8	1.5807e+8	1.8372e+8	9.0884e+7	1.4004e+8	1.8567e+8	1.3838e+8	9.0885	1.3301e+8	1.0975e+8	1.33e+8
Average Original Cost	1845.24	3559.32	1805.18	1688.69	1733.60	1504.37	1527.37	1517.95	1955.51	3818.64	1953.614	1927.73
Total cost of building materials	332.08	391.07	486.29	531.52	359.80	516. 64	584.43	505.33	361.51	416.67	394.33	420.29

Figure 51: Comparison of values

CONCLUSION

In conclusion, technophobia arises from the fear of the unknown, which is a universal aspect of human nature. However, avoiding technologies due to uncertainty is unproductive, given their immense potential benefits. Therefore, the goal of this thesis was to acknowledge the inevitability of AI in our lives and to explore its capabilities in terms of architecture. Any technology in its essence arises as an answer to specific request. Therefore, by exploring it in the proposed direction it should be considered as a helpful tool and powerful inspiration source for architects with near infinite potential considering basic principle that says: «If you can break it down into numbers, computers can help»

ANNEX

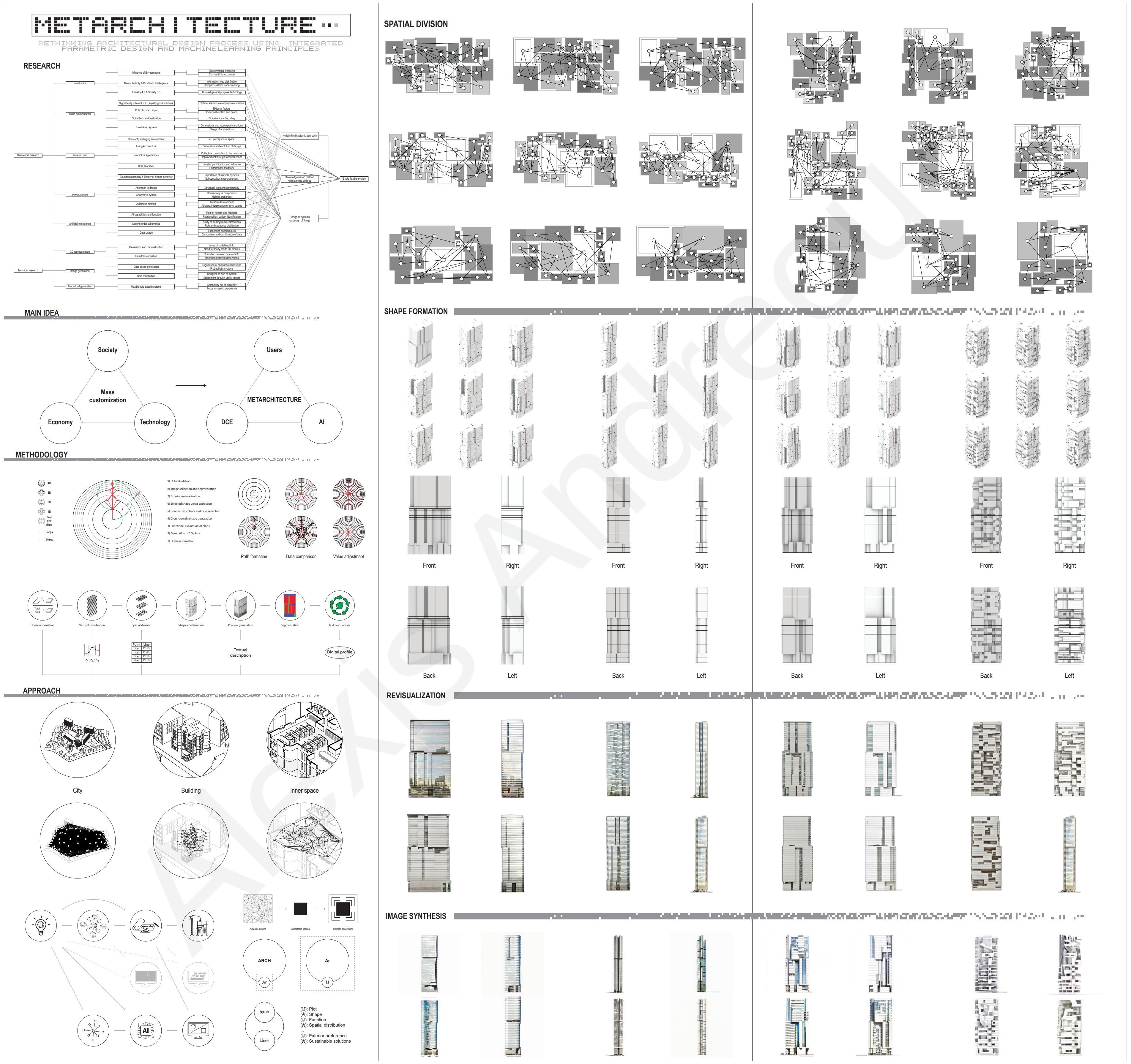


Figure 52: Final presentation panels

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