EVOLVING ARCHITECTURAL PARADIGMS: A STUDY OF LEVELS OF AUTOMATION IN ARCHITECTURE

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Abstract. The Architecture, Engineering, and Construction industry (AEC) is increasingly embracing automation, especially through advancements in Artificial Intelligence (AI). This paper proposes Levels of Automation (LOA) for architectural tasks, categorizing them into creative, documentation and planning, and physically demanding tasks. The study outlines LOA for each category, progressing from basic digital assistance to autonomous machine-driven operations in design and construction. Challenges and implications of varied automation levels are discussed, emphasizing dynamic task allocation based on context, available technology, and task complexity. Decision-making processes are examined concerning the suitability of AI and human intervention. Safety, adaptability, and task-specific considerations are highlighted in selecting suitable LOAs. This paper contributes to the ongoing discourse on automation in architecture, emphasizing the collaborative potential of humans and machines. As automation becomes inevitable in the AEC industry, selecting appropriate LOAs promises enhanced productivity, safety, cost-effectiveness, and overall project quality.

Keywords. Level of Automation, Artificial Intelligence, Generative AI, Adaptive Automation, Architecture.

1. Introduction

The AEC industry is moving progressively towards more automation to address the rising challenges in this sector (Manzoor et al., 2021). Traditionally, automation has been associated with routine and repetitive tasks like those found in factory settings (Sandberg et al., 2016). However, recent advancements in AI have significantly expanded the scope of automation, enabling machines to tackle tasks that were previously considered the domain of human expertise (Altavilla and Blanco, 2020). As research has shown, AI can not only be used to manage repetitive tasks but also

ACCELERATED DESIGN, Proceedings of the 29th International Conference of the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA) 2024, Volume 3, 79-88.

contribute to decision-making processes (Belem et al., 2020). With the fast evolution and adoption of automation technologies, a question arises: To what degree can architectural tasks be automated and what will be the impacts of higher automation?

The discourse on levels of automation began with Sheridan and Verplank's pioneering discussions on the subject in 1978 (Altavilla and Blanco, 2020). LOA or degree of automation can be defined as task allocations between humans and machines (Salmi et al., 2015). In other words, interaction and cooperation between humans and machines can be expressed by various levels of automation (Vagia et al., 2016).

Researchers across various domains, including advanced manufacturing, avionics, train driving, and robotics, among others, have outlined multiple levels of automation (Habib et al., 2017; Vagia et al., 2016). The early impact of adopting automation in different industries has been evident in saving manual labour, consequently enhancing productivity by reducing energy consumption and material waste. Moreover, automation has yielded significant benefits, notably improvement in quality, accuracy, and precision of tasks (Vagia et al., 2016). However, there are significant differences between architecture and the mentioned fields. Architecture encompasses a broad spectrum of activities, ranging from creative thinking, documentation, scheduling, fabrication, and construction tasks, often within unstructured and unpredictable environments.

While the trends show that the AEC industry is progressively automating its processes a clear framework to help guide and show to what extent it should be implemented is missing. Despite the old presence of the concept of LOA in various domains, its application within architecture, needs to be defined and scrutinized. This paper aims to address this gap by proposing a suitable LOA framework specifically designed for the field of architecture.

The research questions guiding this study are as follows:

RQ1) What defines an appropriate LOA framework for architecture?

RQ2) How do LOA affect decision-making processes and influence design outcomes?

This opinion paper aims to propose a suitable LOA framework for architecture and subsequently examine its implications and challenges in the following sections.

2. Background

Architectural projects vary in scale and complexity, from a small pavilion to a large skyscraper. Despite these differences, certain tasks remain common across all projects, including schematic design, design development, documentation, scheduling, fabrication, and construction. These activities can be categorized into distinct groups based on their inherent nature.

In the life cycle of an architectural project, regardless of its scale and scope, two major phases exist: 1) design and construction 2) operation and maintenance (Rafsanjani and Nabizadeh, 2023). This paper will exclusively focus on the design and construction phase, without delving into considerations related to the subsequent operation and maintenance stage.

Given the intricate and varied nature of activities within an architectural project, this paper will specifically address three categories that can be automated:

1. Creative Tasks: Encompassing activities involved in idea generation, conceptualization, and design creation.

2. Documentation and Planning: Encompassing essential activities linking design to construction, such as document creation, Building Information Modelling (BIM), and technical drafting.

3. Physically Demanding Tasks: This category involves labour-intensive tasks such as fabrication and construction such as bricklaying, assembling structures, concrete casting, and similar activities that require physical labour.

2.1. DESIGN AND CREATIVE TASKS

Architectural design typically involves different stages, including schematic design and design development, often requiring the generation and evaluation of multiple design alternatives. Pre-computer practices relied solely on human creativity and demanded substantial labour for creating each design variation, thereby limiting exploration due to constraints of time and budget (Grobman et al., 2010). The shift to computer-based design introduced two key changes: improved drafting capabilities enabled quicker exploration of diverse alternatives, and the utilization of computer processing power facilitated the generation and assessment of design options (Grobman et al., 2010). Furthermore, the adoption of parametric modelling made the design alterations faster and cheaper (Caetano and Leitao, 2020). Finally, integration of generative approaches can effectively address design challenges, such as generating building plans, building forms, designing facades (Sonmez, 2018), and optimizing structural designs.

2.2. DRAFTING AND DOCUMENTATION

One of the global challenges encountered in architectural projects is facilitating communication and collaboration among various stakeholders, including architects, engineers, managers, and workers (Rafsanjani and Nabizadeh, 2023). Given the construction industry's heavily reliance on documentation as primary method for sharing information (Sandberg et al., 2016), a considerable amount of time within architectural projects is dedicated to generating necessary documents for planning and design purposes. It is worth noting that the quality of the design documents can profoundly impact the successful progress of projects (Assaf et al. 2018).

2.3. FABRICATION OR CONSTRUCTION TASKS

The construction process is characterized by its complexity and numerous variables. High level of complexity and substantial costs of construction projects necessitates a keen focus on efficiency (Assaf et al., 2018). While conventional construction methods heavily rely on human labour, the emergence of Construction Automation (CA) shifts the paradigm toward machine-centric approaches (Bock, 2015). Although CA technology is currently in its early stages, there is potential for it to evolve toward the autonomous production of buildings in the future (Chen et al., 2022). By using automatic machines together with robust IT solutions, the construction industry can potentially achieve more successful automation, particularly in the manufacturing of prefabricated concrete elements (Neubauer, 2017). Bock (2015) suggests that robotic technology will play a major role in shaping the future of construction.

3. The Proposed Taxonomy

The suggested LOA in this paper is based on input levels from humans, which defines the independence of the machine in assigned tasks. Most LOAs have been defined along a spectrum between fully manual and fully automated tasks, with a continuum of intermediate levels in between (Vagia et al., 2016). At lower levels of automation machines need more input from the humans, while in higher levels of automation, machines require greater human input, whereas at higher levels, tasks are performed with minimal human intervention.

3.1. LOA FOR CREATIVE AND DOCUMENTATION TASKS

The proposed LOA for design and creative tasks defines five distinct levels, each representing a progression towards greater machine involvement and reduced human input.

At the initial level, design and documentation tasks are done manually, as designers rely solely on their own skills without computer assistance.

The second level sees the integration of digital tools such as CAD software which helps in automating basic drawing, modelling, and drafting tasks.

Advancing to the third level, the integration of parametric design methods facilitates the generation of numerous design options and makes changing design parameters easier. This method empowers designers with flexibility to choose from a diverse array of design options, enhancing decision-making process more dynamic and creative.

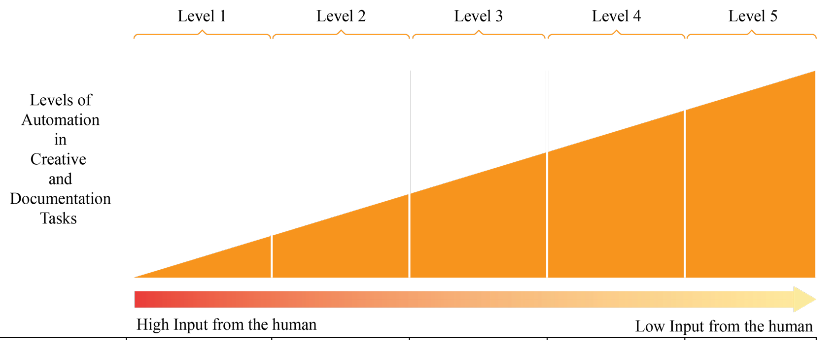
Moving to the fourth level, computational power aid human designers in making optimal decisions through simulation and optimisation techniques, effectively narrowing down the design options.

In the fifth and final level, not only does the computational power aids human in production of design outcomes in shorter amount of time, but the communication with computers becomes much easier, as designers can use natural language to send commands to the computer and the AI system. At this point Generative AI (GAI) tools create designs with minimal inputs from humans. A successful example of generative AI technologies in automating design are Generative Adversarial Networks (GANs) (Wu et al., 2022).

Although the integration of GAI in design tasks holds promise, it is still in the development stage and its current utilisation is limited to the initial stages of the design process. As further advancements are made, we anticipate the emergence of more sophisticated GAI capabilities, enabling their application in later stages of design and facilitating the production of high-quality documentation for design outcomes.

As depicted in Figure 1, the path of automation is linked to the reduction in human input levels, from manual labour to the utilization of generative AI tools. This not only saves time but also enhances design outcomes, empowering designers to tackle more intricate projects within shorter timeframes.

This trend underscores a shift in the role of human designers, from operators to supervisors, as higher levels of automation progressively displace manual tasks with intelligent machine assistance.



Technology	**Manual**	**Digitalization (CAD, BIM & VR)**	**Parametric Design**	**Computational & Generative Design**	**Generative AI**
Description	All tasks are done manually (e.g. sketching, drawing, model-making, etc.)	Most tasks are done manually but with more efficiency using digital tools Computers assist designers in automating tasks(e.g. copy, paste, array,etc.)	Parametric design enables creating large number of design options. Humans should define design parameters and select the desired outcome from options	Computers can generate and narrow down design options to a few and suggest the best options (e.g. simulation and optimisation tools)	Pretrained AI models can generate design options with minimal input from humans. Humans can communicate with computers with natural language

Figure 1 Different levels of automation for design and documentation tasks

3.2. LOA FOR FABRICATION AND CONSTRUCTION TASKS

Fabrication and construction tasks are another important group of activities that can benefit from various LOA. The proposed LOA for these activities defines six levels, each representing a progressive integration of automation into the construction process.

At the beginning level, manual work, humans undertake difficult tasks using basic tools and machinery. In the second level, Computer-Aided Manufacturing (CAM) technology and computer-controlled machines assist humans in making different parts of the buildings or structures either partially or entirely. This level also emphasizes the potential for standardization and modularization of building elements to streamline the construction processes.

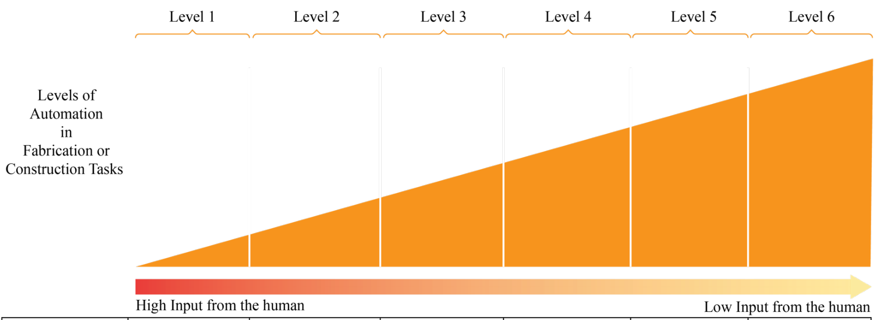
Moving to the third level, digital fabrication techniques enable mass customization and robotic assembly. Robots are introduced to undertake tasks traditionally performed by humans, such as welding, bricklaying (Saidi et al., 2016), and 3D printing. However, precise programming is essential to ensure accurate task execution by these robots.

Advancing to the fourth level, the integration of sensors into robots and construction sites enables the collection of real-time data, facilitating the creation of a dynamic workflow. For instance, Unmanned Aerial Vehicles (UAVs) can be employed for surveying construction sites (Turner et al., 2020). Although robots still require human programming, they exhibit some adaptive behaviours.

Proceeding to the fifth level, AI-driven robots equipped with machine learning capabilities and sensory inputs such as vision and 3D scanners can acquire skills and gain a degree of agency and autonomy. Nevertheless, human supervision may be required for evaluating certain tasks (Habib et al., 2017).

At the sixth and the last level, autonomous intelligent robots can construct structures independently (Turner et al., 2020). While this technology is still under ongoing research and is in its early stages, some examples of autonomous 3D printing of basic structures can be found in the literature such as the work of Zheng et al. (2022).

Figure 2 illustrates LOA in fabrication or construction tasks, depicting the evolution towards greater automation and autonomy in the construction domain.



Technology	Manual	CAM & Prefabrication	Digital Fabrication & Robotic Fabrication	Sensors, Digital Twins & Augmented Reality	AI + Robots	Autonomous Intelligent Robots
Description	Everything completely relies on human skills. All tasks are done manually with traditional tools or machines.	Most tasks are done manually but with more efficiency. Machines are used to make building elements in part or whole with lower human effort. (e.g. prefabrication, standardisation, modular construction, teleoperation)	Some tasks can be done by robots either partially or completely. Human expertise is required to program the robots. Mass customisation can be achieved.	Robots can have adaptive behaviour. Humans and robots can work alongside each other. Human expertise is required to program the robots. Monitoring the construction sites can be automated	Robots can perform complex tasks with minimal input from humans. Machines can learn and act in unstructured environments. Humans can communicate with robots by natural language.	Swarms of robots will make structures independent from human involvement or direct command.

Figure 2 Different levels of automation for fabrication or construction tasks

4. Challenges and Implications

Several activities within architectural projects can benefit from varying degrees of automation. This diversity necessitates a flexible and adaptive selection of LOA due to the intricate and dynamic nature of such projects. Task allocation between humans and machines is not rigid; rather, it is context-specific and subject to adaptation (Vagia et al., 2016). Consequently, different phases of a project may require different LOA. Figure 3 illustrates the characteristics of each Level of Automation (LOA) along with the corresponding technologies and their relevance to both design and construction tasks. In the following section main challenges about integration of higher LOA will be discussed.

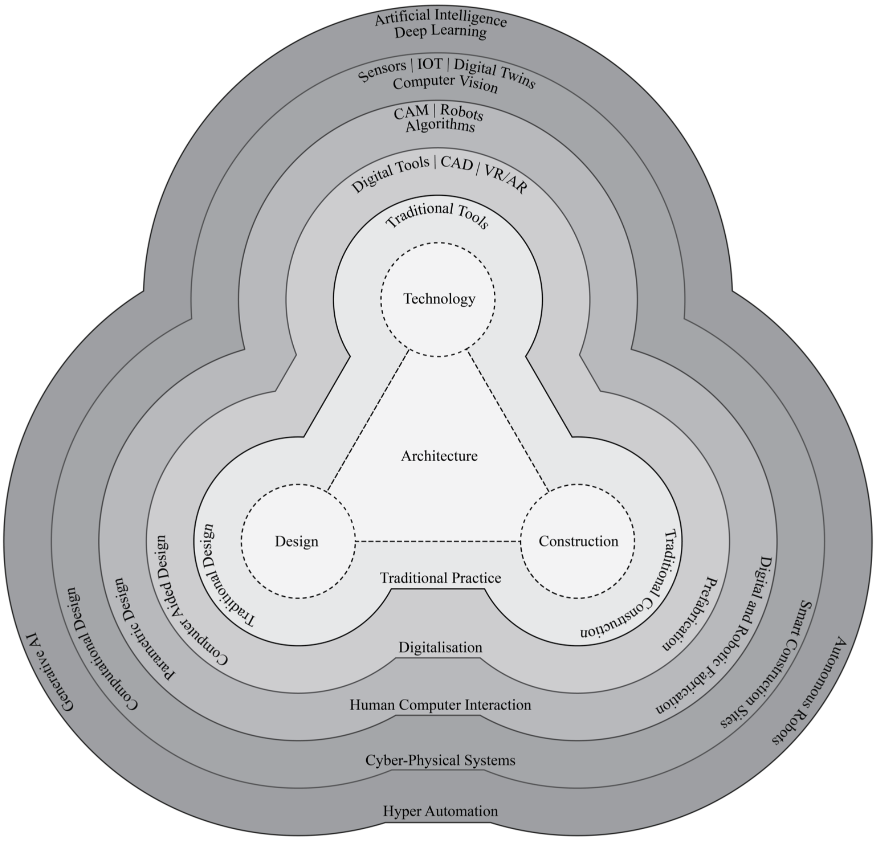


Figure 3 A glimpse of different technologies in different LOA and their associated approaches in design and construction tasks.

4.1. AVAILABILITY OF HARDWARE AND SOFTWARE

An important factor in determining the appropriate LOA is the availability of hardware, software systems and knowledge (Sandberg et al., 2016). Right choices regarding LOA withing a project can lead to higher safety, security, and performance in the lifetime of a project (Habib et al., 2017). For example, in design tasks, human intuition can be the starting point of design exploration, supplemented by computational design methods (Caetano and Leitao, 2020).

4.2. IMPACT ON DESIGN OUTCOMES

The adoption of higher LOA in architectural design can have significant effect on the creative and innovate aspects of design outcomes. While automation tools can expedite the design process and generate a wider range of design options, there is a risk of compromising the uniqueness and originality of designs. Computational design processes often prioritize efficiency over creativity, potentially leading to standardized or formulaic design solutions that lack the human touch. Despite advancements in modern text-to-image AI tools like Midjourney, lookX, and Stable Diffusion, which have demonstrated capabilities in producing creative outcomes, they may overlook other crucial design considerations such as functionality and economic and technical feasibility.

4.3. IMPACTS ON DECISION-MAKING

The impact of varying LOA on decision-making processes in architecture is significant. Challenges such as uncertainty, complexity, and equivocality are inherent in decision-making tasks within architectural projects (Jarrahi, 2018). Analytical decision-making benefits from the computational power of AI in processing vast amounts of data to derive optimal solutions. However, intuitive decision-making, characterized by imagination and creativity, remains a strength of human cognition.

4.4. LACK OF SITUATION AWARENESS

One of the main concerns about higher level of automation is lack of situation awareness and loss of vigilance for the humans (Habib et al., 2017). given the limitation of the current technology and the nature of construction jobs still human supervision seems undeniable. AI is less viable in unpredictable and uncertain environments and their lack of common sense (Jarrahi, 2018).

4.5. IMPACT ON DATA PRIVACY

Another important challenge that arises with the adoption of AI in architectural design is the potential compromise of data privacy and security (Elliot and Soifer, 2022). As AI systems become increasingly involved in the design process, there is a growing concern about the protection of sensitive project information and intellectual property rights. Design firms must grapple with the complexities of safeguarding client data while leveraging AI tools for enhanced design capabilities.

5. Conclusion and Future Research

In conclusion, this paper has outlined the Levels of Automation (LOA) framework in architecture, highlighting its potential benefits and challenges. By categorizing architectural tasks into creative, documentation and planning, and physically demanding tasks, this framework offers a structured approach to implementing automation in architectural practice.

With the advent of modern technologies such as digital twins, construction robots, and AI, further automation in the AEC industry seems inevitable. However, the adoption of higher levels of automation raises important questions about creativity, human intervention, and ethical considerations. Future research in this area could delve deeper into the intersection of automation and architectural creativity, exploring how AI-driven design processes can balance efficiency with innovation. Additionally, studies examining the socio-economic impacts of automation on the architectural workforce and the broader construction industry would provide valuable insights into the implications of automation in practice. By addressing these research gaps, scholars can contribute to the ongoing discourse on automation in architecture and inform the development of responsible and sustainable automation strategies for the future. Human-machine cooperation is an extensive topic, and this paper did not intend to get deep into the concepts and just scratched the surface. Validations can show the limits of the approach and suggest improvements to the proposed model.

Acknowledgements

This work was supported by Building 4.0 CRC. We also thank Queensland University of Technology (QUT) for the scholarship assisting this research.

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