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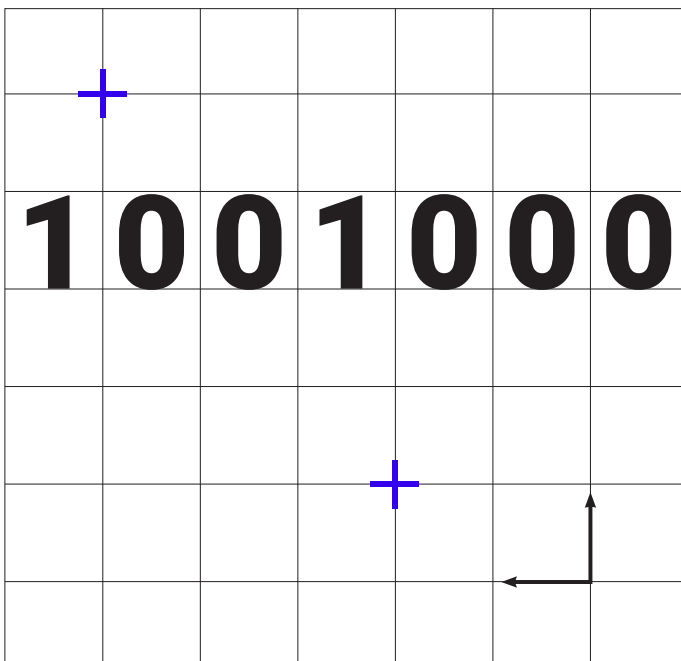
# CHAPTER 03

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Artificial Intelligence as a design  
tool in the architectural design  
process

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Hanke Tobias, Grunwald Gregor



# Introduction

The architectural design process describes the attempt to solve an urban or architectural problem holistically. Architects have always used a variety of tools to communicate their ideas. However, since the 1990s, the digitalization of the construction industry has meant that analogue tools, such as tracing paper and pencil, have increasingly been replaced by digital tools (**Drach, 2016**). As a result of the digital transformation of the construction industry, it is now almost inconceivable for most architects to plan the design and execution of a construction project without the support of computers, as the complexity of larger objects requires a smooth exchange of data between the planners involved (**see Bielefeld in Krebs, 2007**). Digital planning methods such as Building-Information-Modeling (BIM) provide the basis for the creation of digital building models using computer-aided systems (CAD) and enable the implementation of a variety of technologies for different use cases. In addition to use cases such as parametric design, construction site robotics, or energy optimization, artificial intelligence (AI) has been used by architects for some time as a tool in the design process. BIM is already an essential foundation for the implementation of AI (**Abioye et. al. 2021**).

In combination with BIM, AI already provides support in areas such as planning, execution, and the utilization phase (**see, for example, Cho et. al. 2019**). Due to the increasing number of use cases through the development of new technologies, there is a strong growth in the selection of further digital tools. However, this growth has led to a lack of digital expertise in many organizations, which has led to increased inefficiencies in recent years (**Nikas et al. 2007; Bello et al. 2021**). In the context of this evolution and its many possibilities, this chapter describes and evaluates the use of AI as a digital tool in the architectural design process.

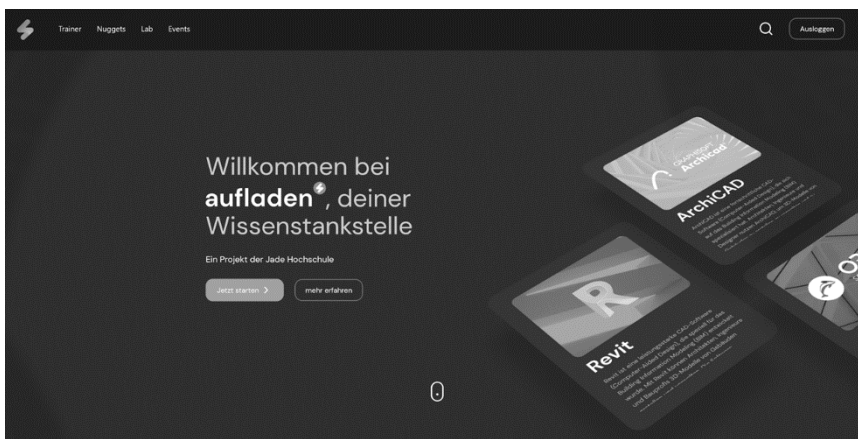
To this end, an architectural design study using AI with machine learning was used to investigate the extent to which AI can be used as a digital tool. The evaluation of the results provides information on whether AI can be used as a design tool and where the limitations of the current state of development lie. This process was tested as a hypothesis on the basis of the quantitative, practical investigation.



The chapter provides an outlook on the influence of AI on the design process and how the influence of digitalization and the use of digital tools is changing this process and at the same time opening up new design possibilities.

The study also shows that digitalization not only affects the day-to-day work of architects, but also all academic courses that deal with building design. New training formats for digital technologies have long since had to be developed and integrated into existing curricula (**Grunwald et. al. 2022**). Against this background, the AUFLADEN research project (**Fig. 1**) has been developing a suitable teaching and training concept for teaching digital planning, in particular BIM, the didactic preparation of learning content and the scientific evaluation of new concepts since 2022. The project is funded by the Foundation for Innovation in Higher Education as part of the FREIRAUM 2022 program.

The 25-month project serves as a central contact point for students who want to learn about and try out BIM. This is done through self-developed teaching and learning formats such as the BIM Nuggets, the BIM Trainer and the final BIM Game, a fictitious simulation game that simulates an ideas competition for the design of a building (**Grunwald et. al. 2022; Bhat et. al. 2022; Heins et. al. 2021**). The digital portal ([www.wissen-aufladen.de](http://www.wissen-aufladen.de)) is continuously developed and current topics are investigated with the active participation of students. The experimental space for this is the AUFLADEN LAB, which is used for learning and teaching digital technologies in building design (**Hanke et. al.; Kawasaki et. al.; Tasnia et. al., 2024**). Through research-based learning and teaching, students develop solutions for various use cases together with experts in the field. In addition to exploring topics such as Augmented Reality (AR) (**Hanke et. al. 2023**), Robotic Automation Processes (RPA) (**Grunwald et. al. 2023; Heins et. al. 2024**), a central theme of the LAB is “Artificial Intelligence in the Design Process”.



**Figure 01:** Homepage of the browser-based training platform AUFLADEN (developed by Hanke T.)

In general, artificial intelligence can be described as computer systems that have the ability to autonomously solve customer-specific tasks that, due to their complexity, could previously only be solved by human skills. The applications can be on PCs, tablets or smartphones, but also robots in embedded systems or wearables, etc. One example could be self-driving cars in the future. **(Gethmann et. al. 2022)** They can be used in different ways. The release of the AI models Chat GPT and DALL-E, published by the company OpenAI, has brought even more attention to AI since November 2022.

Using the two text-to-text and text-to-image generators, human-like responses in the form of unique texts and images can be generated within seconds based on text input, colloquially known as prompts. What initially appeared to be a technological trend is still influencing the daily work of architects and engineers today and has already gained widespread acceptance due to its wide range of possible applications. AI has become indispensable and can significantly simplify various work processes if used correctly. **(Silberer 2023)** Against this background, the motivation arose to investigate in which phases of the architectural design process AI can be used as a digital tool within the framework of a case study.

Similar to other IT application scenarios, the use of AI faces the challenge that it is a changing field of innovation that is constantly changing. **(Deckart et. al. 2020)** It should therefore be noted that AI has evolved since the completion of this study. Today, artificial intelligence is already being used in a more targeted way for more specific use cases and has been added as an additional tool in various software solutions. Therefore, at the time of the study, browser-based AI models were the preferred choice for exploring AI applications.

For the case study, the architectural design process was first analyzed and generalized to provide a basis for developing specific questions. By assigning different tools within the architectural design process, suitable AI models were selected that could be relevant for the use case. In addition, individual studies were conducted on the questions using different AI models. The results were then used to determine where in the design process AI could be applied.

The outlook at the end of the report provides suggestions on when and how it makes sense to use AI in the creative process of architects and engineers, and also describes the importance of exploring new technologies in the context of digital transformation in order to expose future architects and engineers to current issues at an early stage and sensitize them to dealing with them.

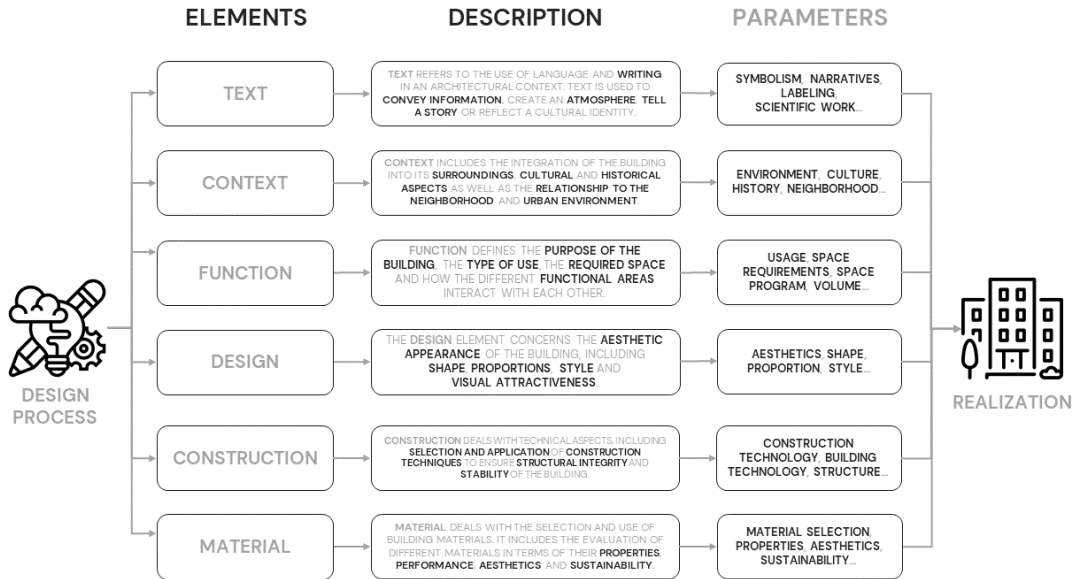


Figure 02: Division of the design process into elements & parameters (developed by Hanke T.)

## Architectural design analysis

For the case study, the architectural design process was analysed and generalized to provide a basis for developing specific questions. By assigning different tools within the architectural design process, suitable AI models were selected that could be relevant for the use case. In addition, individual studies were conducted on the questions using different AI models.

The results were then used to determine where in the design process AI could be applied. The outlook at the end of the report suggests when and how it makes sense to use AI in the creative process of architects and engineers. Based on Bielefeld, the design process is described as follows: "Design is a process that is difficult to force into systematized paths or typologized processes. Especially when you are a student taking your first steps in your own world of design and idea generation, designs emerge from a variety of approaches and influences according to the principle of trial and error.

You try something and often find that the idea is not going anywhere. In most cases, this leads to new alternatives or new paths that seem interesting. In this process of stimulation, moments of happiness, dampening and frustration, the awareness of the planning task is consolidated and a design is created.” **(Bielefeld et. al. 2007).**

It also emphasizes that architecture is not created in a vacuum, but usually in response to the context in which it is to become a structural reality. It encompasses functions, gives expression and design to a task, and can be experienced through its construction and materiality. **(Bielefeld et. al. 2007).** Bielefeld’s derivation of the elements of context, function, design, construction, and material forms the basis for generalizing the design process. Parameters were derived from keywords in the definitions of each element, which in combination represent any design with the intention of realization. **(Fig. 2)**

Based on this development, design tools have been assigned to these parameters. Architects and engineers have always used tools for visual communication. Today, due to the influence of digitalization, digital tools are mainly used, such as CAD software for modelling 3D models or rendering software for creating realistic visualizations of a planned object. However, the term “design tools” does not describe conventional tools; rather, it is a metaphor that transfers the image of a hand tool to complex issues in order to communicate ideas more effectively between project participants during the design process.

In the context of the case study, this metaphorical transfer allows for differentiation from the perspective of an individual architect who wants to justify his design approach or describe a specific design methodology **(Gänshirt, 2011).** By determining the tools from the derivation of the parameters, an assignment to the respective elements is created.

Furthermore, by selecting a specific tool, suitable AI models were selected and their usability in the design process was examined. **(Fig. 3)** In the following, the detailed implementation of the developed methodology is described and illustrated by means of two examples.

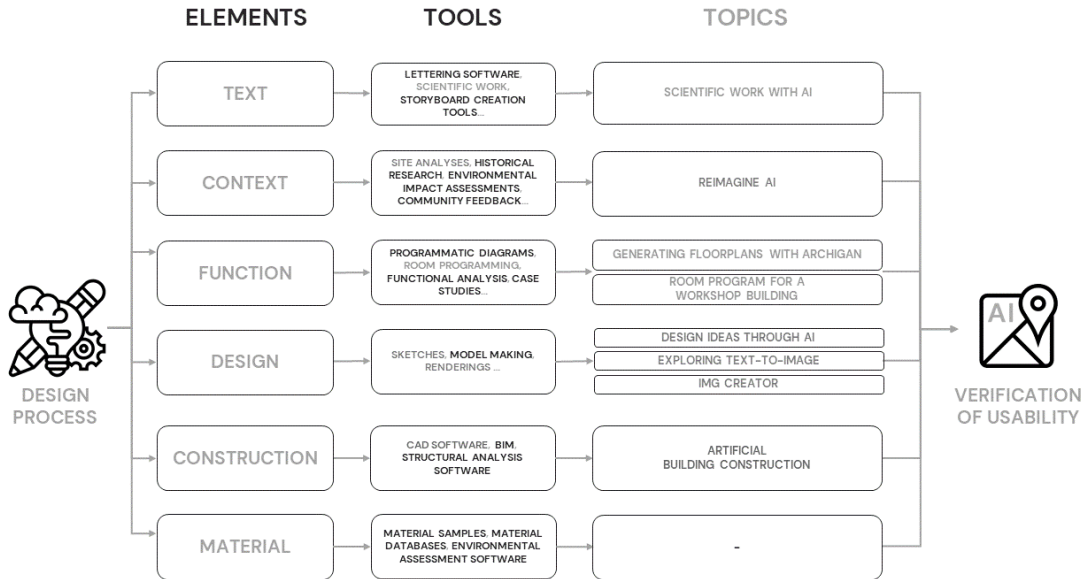


Figure 03: Assigning tools for topic development (developed by Hanke T.)

## Method

To conduct the case study, various AI models were used, primarily browser-based text-to-text and text-to-image generators, to determine whether they could be used in the design process. The focus was on analyzing whether their application could optimize the work process. This was done by entering prompts to generate answers that should correspond to the user's descriptions.

The AI decomposes the entered text modules into semantic elements and generates corresponding results using generative models. The results were then analyzed for accuracy. If the answers were not sufficient, the process was repeated, optimizing the requirements until the result was sufficient for further use, or it was determined that the selected AI model was not capable of generating sufficient results. The final results were used to identify advantages and disadvantages and to evaluate whether the corresponding AI model could be used in the design process for the use case under investigation.

## Case Study 1: Text-to-Image

In the first case study, the AI model DALL-E 2 was used as a text-to-image generator for the topic “artificial building constructions” to determine whether it could be used to generate structural details. By entering text modules that describe the exact structure of a desired detail, the AI was tested for its ability to generate structural details according to the user’s requirements, in order to save time in the use case for developing such details and to optimize the design creation process. The figure (Fig. 4) shows the final result of the case study.

The structural detail of a wall construction with the following layers was requested: lime sand brick 11.5 cm, polyethylene foil 0.2 mm, air layer 5 cm, mineral wool insulation 10 cm, air layer 2 cm and brick facing 7.5 cm. It was also described that the result should look “very detailed”. By analyzing the generated image, it was assessed that DALL-E 2 is capable of generating an image that could remind a construction industry viewer of a structural detail.

However, it is not able to generate structural details that can be further used in the design process. It was considered an advantage that the AI model attempts to respond to the scale of the representation and that its application is intuitive and accessible.

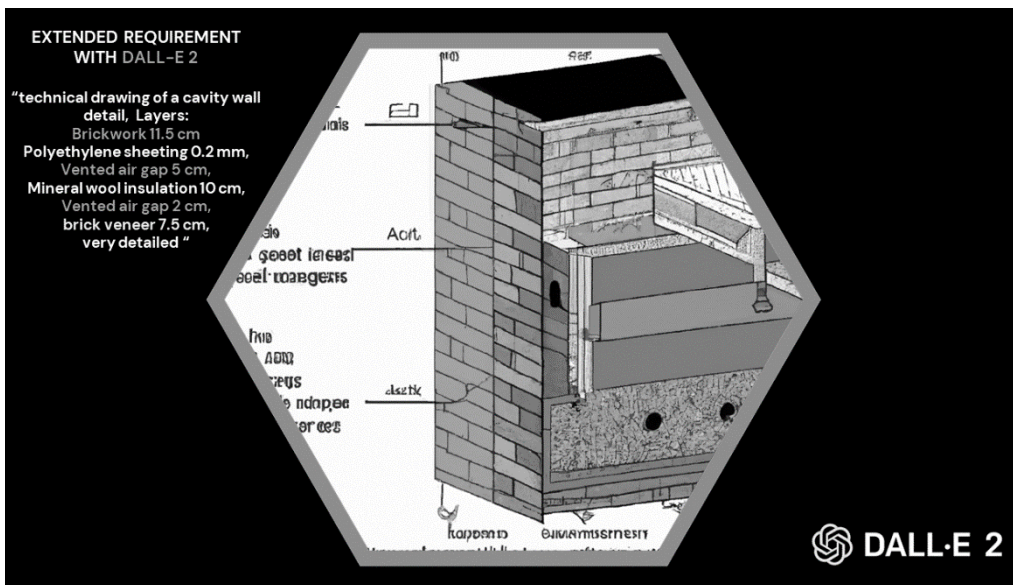


Figure 04: Final result on the topic: artificial building construction (work by: Haupt A. & Grefer M.)

Due to the abstract representation of the detail, there is a high risk of conveying incorrect knowledge and was therefore rated as insufficient for use in the design process in the area of the structural element.

## Case Study 2: Text-to-Text

The Chat GPT (text-to-text generator) AI model was used for another topic to investigate the suitability of the AI to support the development of a room program for a workshop building. The AI was asked by text input to create a room program with a total area of 650 square meters, taking into account specific parameters, whereupon the AI determined the individual uses and rooms based on the functional requirements of a workshop building. The requirements for multifunctional and common areas were also recorded and taken into account. It was also required that the total area of 650 m<sup>2</sup> be used optimally. According to KI, the layout ensures that all important functions have sufficient space and at the same time there is room for creative exchange and flexible use. To analyze the response, the information was then validated in CAD software to provide an assessment. (Fig. 5)

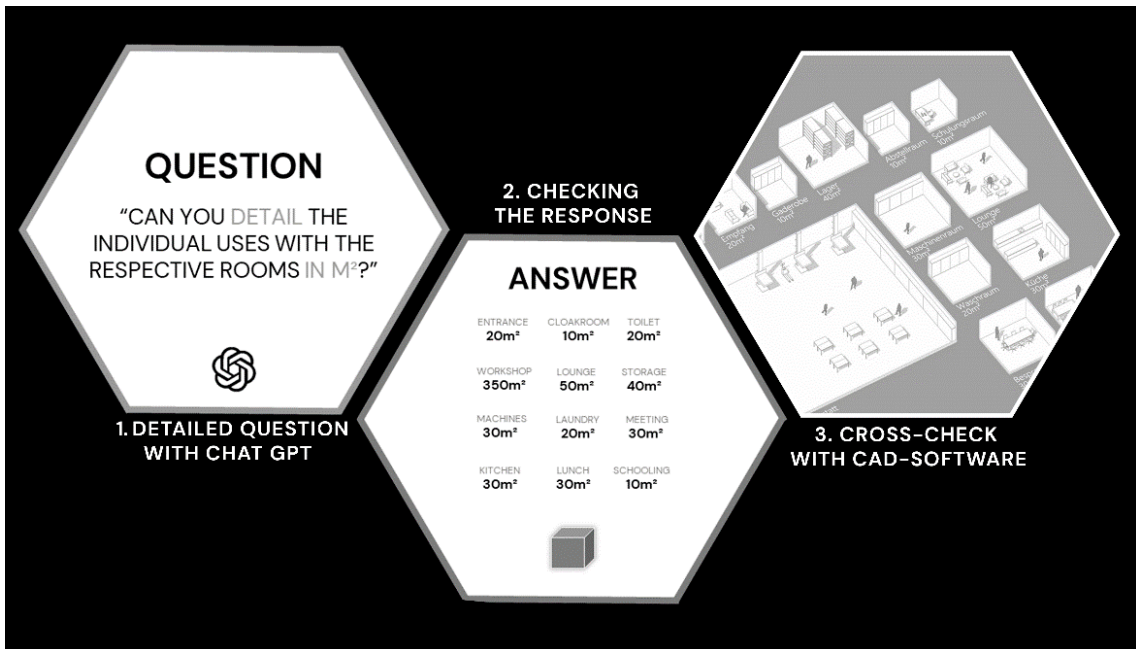


Figure 05: . Final result on the topic: room program for a workshop building (work by: Hoffmann M.)

The final result showed that the Chat GPT AI model can be used as a tool for creating a room program and optimizes the work in the design process. However, it should be noted that the results should always be checked for accuracy in order to avoid passing on incorrect information. After the implementation, all the results were compared with each other to get an overall result on whether AI is used as a digital tool and where it is located in the design process.

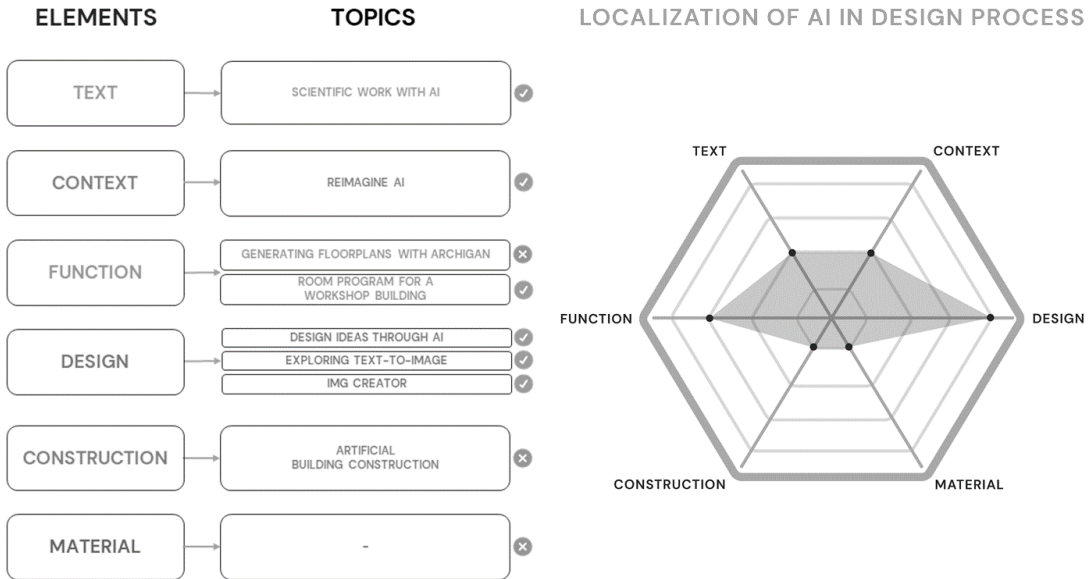
## Result

In general, regardless of its localization, it has been shown that AI models such as text-to-text and text-to-image generators have a high potential to optimize work processes in different phases of the design process due to their diverse, wide-ranging application possibilities. The application of the browser-based AI models that were tested were summarized as user-friendly and intuitive, which makes access easy for a wide range of people from different fields or professional groups without any special prior knowledge. Nevertheless, it should be noted that an AI's answers are only as good as the input of the requirements placed on it. It has been found, for example, that a person with specialist knowledge of the construction industry can make much more specific requests of the AI and thus generate more precise answers than a person with no prior knowledge.

Based on the example shown, it is difficult for a user without specialist knowledge to develop an efficient and target-oriented working method for generating a room program with AI, as it is more difficult to enter requirements and the results are therefore less accurate or even incorrect. Furthermore, this can have the consequence that the risk of spreading false information could increase significantly, as AI does not provide any source information as proof for verification. For this reason, the use of AI in the design process should be done by subject matter experts with sufficient prior knowledge to avoid common errors and consequential errors in later stages of the design.

In addition, the diagram below (**Fig. 7**) shows the result of the localization of AI in the design process. The diagram shows that the use of AI has mainly led to usable results in the work processes of design and functional elements. Based on the results, it can be concluded that AI is primarily used as a tool in those areas of design where there is still sufficient room for interpretation to develop design ideas for an object with the intention of realization. As the design ideas are consolidated until the transition to the realization phase, the technical capabilities of the tested AI models become less sufficient as the requirements become more specific.

# Artificial Intelligence as a design tool in the architectural design process



**Figure 07:** Localization of AI in the design process (developed by Hanke T.)

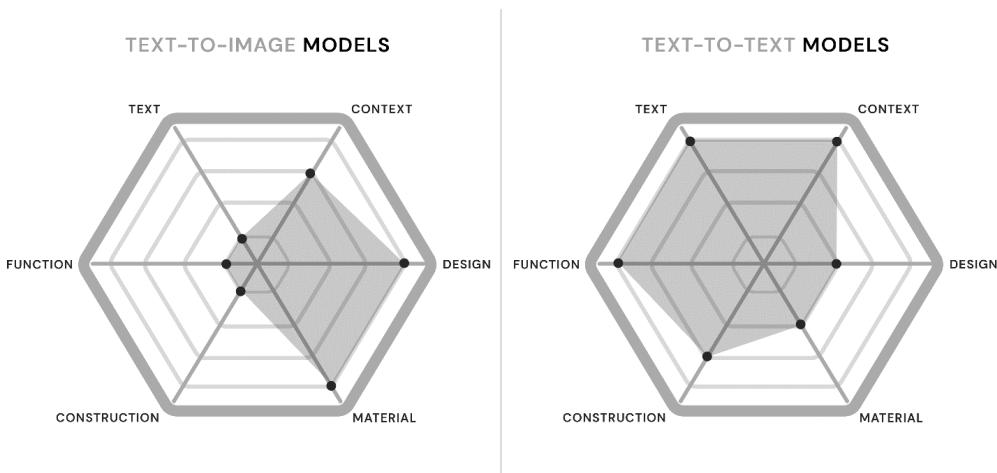
Furthermore, it was found that due to the variety of possible applications, the localization of certain AI models cannot be precisely assigned to a specific element. For example, DALL-E 2 was found to be unsuitable for generating structural details, but could be used to generate initial perspectives for brainstorming a design or initial facade studies to investigate certain materials. This means that DALL-E 2 can be assigned to two elements of the design process at the same time, being used in design and material.

In response to this finding, the matrices in the following diagram (Fig. 8) show the localization of the text-to-text and text-to-image generators in the design process and illustrate the weighting of their usability in the different elements. It can be concluded that the use of text-to-text generators reflects a very versatile application function in the design process, but that their lack of a function for displaying text modules in the form of images reduces their use in design and material elements. Text-to-image generators, on the other hand, compensate for exactly this circumstance, which means that the application can cover a wide range of use cases in the design process by combining the two AI models and deciding when and where to use which model depending on the use case.

AI models such as text-to-text and text-to-image generators have demonstrated their ability to optimize design workflows. The application of these models is user-friendly and accessible to a wide range of users, as they do not require any special prior knowledge. However, the quality of AI-generated results is highly dependent on the input requirements, which means that specialized knowledge is required for more accurate and useful results. Without the necessary expertise, it is difficult to use AI efficiently, which can lead to inaccurate or incorrect results. By analyzing the localization in the design process, it can be said that AI is mainly used in the early stages of the design process.

The more specific and detailed the requirements become, the less suitable the current AI models are. An example is DALL-E 2, which is good for idea generation and facade studies, but not for detailed building designs. The combination of text-to-text and text-to-image generators can cover a wide range of use cases in the design process if used correctly, taking into account the strengths and weaknesses of each model. This allows for a flexible and needs-based use of AI technologies at different stages of the design process.

### LOCALIZATION OF SPECIFIC AI MODELS IN ARCHITECTURAL DESIGN PROCESS



**Figure 08:** Result for locating AI models in the design process  
(developed by Hanke T.)

Finally, it should be noted that it has been shown that no AI model is able to completely take over certain work steps. Rather, the browser-based AI models should be seen as a tool to support and optimize the design process. In the context of the digitalization of the construction industry, it can be seen that the possibilities offered by AI could be responsible for further shaping the construction industry in the long term. The emergence of AI can greatly optimize the way certain work processes are carried out by architects and engineers in certain phases of the realization of a project, thus changing the construction industry in the long term.

### **Outlook**

Considering the time it took to determine the above results, it is clear that AI has now found its way into various software solutions as tool. The company Adobe, for example, reacted quickly to the first developments and integrated AI as a tool into various software solutions such as Photoshop or Illustrator. AI models such as Veras can also be added as a plug-in to CAD software solutions such as Autodesk Revit and used to create perspectives using the CAD software. However, the same conclusion can be drawn here as from the results of the case study. For correct application, it is essential to have sufficient knowledge of the respective program in order to integrate artificial intelligence as an efficient and targeted tool into the design process.

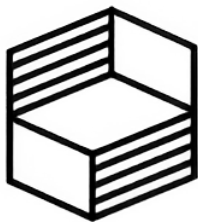
With these findings and the rapid development of AI in relation to specific use cases in the design process, the question arises as to how AI can be used in other application areas of the construction industry where difficulties arise in the design of complex parametric objects due to a lack of specialist knowledge or digital skills. Digitization is making the use cases of architects and engineers more diverse and, above all, more specific. Due to the growing interdisciplinary, the needs of many different disciplines, not only those of civil engineering, are required to realize increasingly complex building projects. It would therefore be interesting to consider whether AI can contribute to minimizing the skills shortage by studying certain disciplines, such as civil engineering programming, in relation to the design process and testing whether AI is suitable for creating generative data codes for further use in software solutions such as Rhino and Grasshopper.

Finally, it should be mentioned that current topics in the digitalization of the construction industry, such as AI, require rapid integration into university education and training programs due to their importance. It is important to sensitize students to the use of new technologies at an early stage in order to reduce errors in the creative process, optimize the work process and ensure a technological advantage in professional life. The research results were also exhibited at last year's University: Future Festival.

Three days dedicated to the future of higher education. Under the motto Heads Up!, The University: Future Festival (U:FF) took place from April 26 to 28, 2023, in both real and digital space. The motto was: Digital First! The entire festival in all its diversity and the associated supporting program could only be experienced online. At the same time, physical stages at various locations in Germany offered the opportunity to meet and network in person. The results were exhibited live on site in the Patricia Lumumba Gallery and can also be viewed in a digital replica of the gallery in the form of a 3D tour via a web link (<https://aufladen.projekt.jade-hs.de/UFF23/>).

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*Figure 09.* Logo „Stiftung Innovation in der Hochschullehre“

## Conflict of Interests

The author declares no conflict of interest.

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