THE WHAT, WHY, WHAT-IF AND HOW-TO FOR DESIGNING ARCHITECTURE

Explainability for auto-completion of computer-aided architectural design of floor plan layouting during the early design stages

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Abstract. In the next thirty years, the world's population is expected to increase to ten billion people, posing major challenges for the construction industry. To meet the growing demands for residential housing in the future, architects need to work faster, more efficiently, and more sustainably, while increasing architectural quality. The hypothetical intelligent design assistant WHITE BRIDGE, based on the methods of the 'metis' projects, suggests further design steps to support the architectural design decision-making processes of the early design phases. This facilitates faster and better decisions early in the process for a more responsible resource consumption, better mental well-being, and ultimately economic growth. Through a case study we investigate if additional information supports the understanding of these suggestions to reduce the cognitive workload of architectural design decisions on the backdrop of their respective representation. The paper contributes an approach for visualising explanations of an intelligent design assistant, their integration into paper prototypes for case studies, and a workflow for data collection and analysis. The results suggest that the cognitive horizon of the architects is broadened by the explanations, while the visualisation methods significantly influence the usefulness and use of the conveyed information within the explanations.

Keywords. Explainability; Artificial Intelligence; XAI; SDG 3; SDG 8; SDG 12.

POST-CARBON, Proceedings of the 27th International Conference of the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA) 2022, Volume 2, 435-444.

1. Introduction

The world population is expected to reach ten billion by 2050 (Statista Research Department, 2020), with about two thirds of the population living in an urban area (United Nations, 2019, p. 19). In order to meet the growing demands for residential housing, architects need to be able to work faster, and more sustainably and efficiently, while simultaneously increasing architectural quality. In order to satisfy these requirements, the decisions of the early design stages are of significant importance for the architectural quality of the constructed building (Harputlugil et al., 2014). Derived from the Vitruvian Principles the authors (Ibid.) define architectural quality as the weighted sum of ‘functionality’ (i.e. use and usefulness for intended purpose), ‘built quality’ (i.e. quality of built substance), and ‘impact’ (i.e. aesthetics, relation to context). The design process is built on controlled convergence, meaning that constantly new ideas and problem solutions are generated and only a selected few are further pursued to run through this process again. Thus, the sooner well-informed design decisions are made, and issues are identified and addressed, the better the final building. Vice versa, the later fatal flaws are recognised within the design process, the more difficult correcting them and changing the design becomes (Buxton, 2007, pp. 146-149). This has impacts on the duration, the quality of architecture, and the sustainability of the entire building of both the design and construction process. Thus, efficient design, designing, and data management of the early design phases can result in an estimated waste reduction of 33 percent (Haeusler et al., 2021, p. 347).

Intelligent systems have been applied in other fields to support the user in completing tasks faster and more efficiently, such as digital keyboards on everyday digital devices, predicting and auto-completing words and sentences. Through adaptation and specific extensions within the workflow of Computer-Aided Architectural Design (CAAD), the methods of intelligent systems have also been applied to support the architect in fulfilling the complex tasks of architecture. Derived from these principles, the 'metis' projects pursue an intelligent design assistant suggesting further design steps for spatial layouting during the early design phases. In the following we propose methods of explainability for such an intelligent system, utilising a hypothetical application called WHITE BRIDGE. With our system, we aim to support architects within the decision-making of the early phases through future interaction methods of intelligent systems and architects. Thus, we facilitate more intuitive work and high quality architecture, while speeding up the process and reducing the work-related stress on architects.

2. Related Work

The field of explainable artificial intelligence (XAI) is a quickly expanding area of research. While Palacio et al. (2021) focus on establishing a consensus and framework for XAI strategies for implementation, Wang et al. (2019) propose a conceptual framework for designing explainability for a specific target group and building blocks for a theory-driven adaptation for any user group.

The framework of Figure 1 is divided into human reasoning process to the left and explainable intelligent system methods to the right. Human reasoning is differentiated into ideal reasoning ('should reason') and true human reasoning ('actually reason with errors’) of heuristic ‘System 1’ and analytical ‘System 2’ (see Figure 1, left). On the right-hand side is the intelligent system which generates explanations through different XAI strategies to support the human reasoning methods (see Figure 1, right). The system answers to both the ideal and true human reasoning with different strategies through either the support of human reasoning or the mitigation of biases of heuristic 'System 1' and analytical 'System 2'. Wang et al. summarise the following four steps to adapt the framework for a specific target group (Wang et al., 2019, p. 9):

- Clarify the user's reasoning goals through a literature review, ethnography, and/or participatory design
- Identify possible biases for the respective applications through a literature review, ethnography, and/or participatory design.
- Deduce appropriate explanation ways for reaching the reasoning goals and/or mitigating cognitive biases using the pathways of the framework
- Integrate the explainable intelligent system facilities to create an explainable user interface

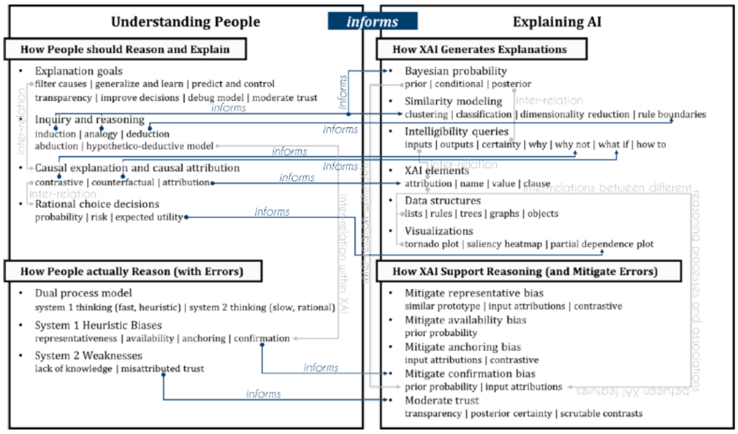

Figure 1. Conceptual framework for reasoned explanations (Adapted from Wang et al., 2019, p. 4)

The common practice of architects of using reference buildings (e.g. floor plans and other visualisations), is a well-recognised approach in architectural design for using exemplary designs with originality and for creating innovation (Richter, 2011, pp. 139-154). Architects use these examples as a basis for their process - as a source of inspiration, design conditions and explicit information, as a tool for evaluation of their own design, and as a medium for communication (Ibid.) - combined with their knowledge from other sources and previous experiences to synthesise new original architectural designs. Considering the similarities between the architectural design process and Case-Based Reasoning (CBR), an intelligent design assistant using reference buildings for suggesting further design steps (i.e. solutions or solution aspects) builds on the same principles, including its design requirements and workflow.

By assuming the position of Harputlugil et al. (2014), the architectural design decision-making process can be described as an orderless analytical hierarchy process

(AHP) with multi-criteria decision-making (MCDM) to design a solution for the unique problem to achieve the best possible quality of architecture (Laseau, 2000, p. 13; Lawson, 2004, p. 90). Thus, the design decisions of the early design phases have significant influence on zarchitectural quality of the final building (Buxton, 2007, pp. 146-149; Harputlugil et al., 2014, p. 140). Derived from the Vitruvian Principles ‘utilitas’, ‘firmitas’, and ‘venustas', Harputlugil et al. (2014) formulate ‘functionality’, ‘built quality’, and ‘impact’, whereat ‘functionality’, with its sub-criteria 'use', 'access' and 'space', is ranked highest on average and architects within their (Ibid.) case study during early design stages. Furthermore, architects aim to create and increase the quality of their design solutions through life-long learning to eventually outline their own design philosophy. These ‘Guiding Principles’ (Lawson, 2004, p. 112) are ‘sets of ideas, beliefs and values that operate for the designer’ (Ibid.), created from a mental collection of reference buildings and personal experiences throughout their career.

In order to provide the best possible human-computer-interaction (HCI) or human-system-interaction (HSI) for architects designing during the early design phases, the interface of the architect and the system should assimilate to the best practises of the respective design stage (Negroponte, 1973). Nevertheless, the design of graphic user interfaces (GUIs) of contemporary CAAD tools and software largely focuses on computer systems as the interaction device, while neglecting sketching as an essential practice of the early design for conceptualisation, visualisation of abstract ideas and communication (Lertsithichai, 2005, pp. 357-358). However, the adoption of users' mannerisms to increase the acceptance and productivity of interactive systems is deeply rooted in the common design principles for user interfaces (Lee, Chuang & Wu, 2011, p. 4), including the ISO standard 9241-210 for user experience (UX) based on User-Centred Design (UCD). This design practice facilitates a short learning process and the mitigation of errors by considering the users’ needs and goals, and improves efficiency and effectiveness of an interactive system. Further, Lee, Chuang and Wu (2011, p. 3) state that the more intuitive and aesthetically pleasing the GUI is for architects, the higher the satisfaction with the application. Consequently, the GUI is the focal point of interaction between architects and an intelligent design assistant.

3. Problem Statement

Contemporary research for intelligent design assistants mostly revolves around CBR and Deep Learning (DL). CBR approaches have been adapted as Case-Based Design (CBD) as early as the 1990s, while the application of DL in the field of architecture is fairly recent, focusing mostly on the mechanisms and the possibilities of the system, e.g. retrieval or design style manipulation. Further, explainability for intelligent systems against the backdrop of a specific target group, such as physicians (Wang et al., 2019), has been researched. However, there is no concept of the nature and communication methods of the necessary information for architects to understand suggested further design steps of an intelligent design assistant aiming to relieve the cognitive workload of the early design phases.

4. Approach

The described vision of an intelligent design assistant aims to mimic the architectural design process of the early design phases by suggesting further design steps of spatial configurations when designing a building's 'functionality'. The requirements and goals for such a system are assumed to be equivalent to those of the common architectural design decision making process. During this process architects apply inductive and analogical reasoning, e.g. explorative creation of alternatives to select the most promising solutions or solution aspects (Laseau, 2000). This kind of reasoning is supported by contrastive (‘Why?’, ‘Why not?’), counterfactual (‘What if?’), and transfactual (‘How to?’) explanations to iterate the priority ranking of selected criteria and sub-criteria, e.g. through pairwise comparison (e.g. tangible/intangible, subjective/objective).

By using the pathways of the framework (see Figure 1) by Wang et al. (2019), explanation methods to support the reasoning process and mitigate errors can be deduced. The latter will be specifically described for the use of reference buildings by architects in a paper of the eCAADe 2022. The findings of the architectural workflow, design requirements, design decision making process and quality assessment on the backdrop of the framework are synthesised into explanation visualisations for the visually driven target group, using common, established and domain knowledge. The strategies of the system itself, e.g. Bayesian probability and XAI facilities, for generating these explanations and their visualisations, will be discussed in detail in a paper planned to submit to an AI conference. The proposed paper prototype of the hypothetical intelligent design assistant WHITE BRIDGE integrates the explanation visualisations without any operational functionality. With the best practices for designing GUIs in mind, the proposed digital paper prototype, integrating suggestions for further design steps by an intelligent design assistant and corresponding explanations for architects, has two main views: the drawing view and the suggestion view, both containing visualisations for facilitating better understanding of the suggestions of the hypothetical intelligent design assistant WHITE BRIDGE. The latter view is pictured with dropped down windows of textual information in Figure 2, followed by a detailed description of the individual explanation visualisations and their purposes.

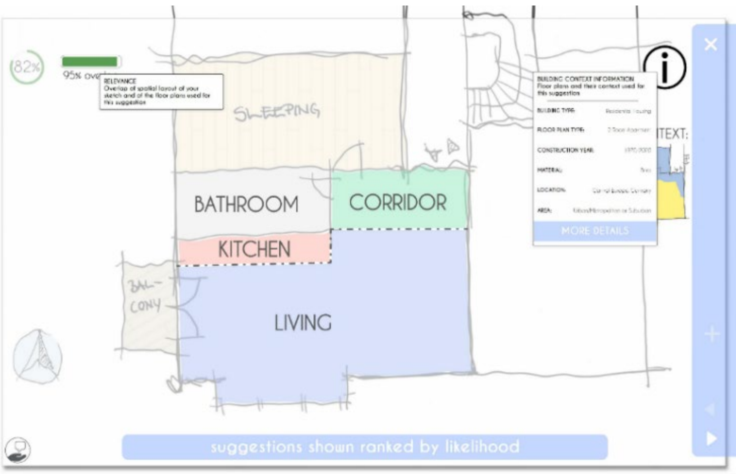

Figure 2. Graphic User Interface of Paper Prototype of suggestion view and opened windows.

For supporting the architect’s design process, the intelligent design assistant WHITE BRIDGE presents suggestions on a top layer mimicking sketch paper for facilitating contrastive comparison with colour coded indicators (see Figure 3, left), while highlighting its suggestiveness. Simulations, e.g. daylight simulations, are suitable for creating ‘What if?’ and ‘How to?’ scenarios for counterfactual and transfactual design decision making, placed on the respective suggestion (see Figure 3, right). Further, by supporting a well-informed criteria ranking within the AHP, possible anchoring bias (Wang et al., 2019) can be mitigated.

Figure 3. Highlighted explanation visualisations for reasoning support.

The mitigation of the representative bias (Ibid.) is enabled by offering the design conditions (i.e. classification and clustering) called ‘Building context information’ of both the floor plans for generating the suggestion (see Figure 2, upper right) and the for the drawn sketch (see Figure 4, upper left) with categories derived from the Cultural Objects Name Authority (CONA) (Harpring, 2019, pp. 65-69). The toast notification 'suggestions shown ranked by likelihood' (see Figure 4, upper right) indicates that the suggestions are presented in the order of prior probability to mitigate possible availability bias (Wang et al., 2019). For mitigating the heuristic bias of confirmation (Ibid.), the architect is offered a health bar with colour coding (see Figure 4, lower middle) representing the matching (i.e. similarity) of the sketched floor plan (e.g. room adjacencies) and the floor plans for generating the suggestion.

Figure 4. Highlighted explanation visualisations for mitigating heuristic biases.

Transparency, scrutability and debugging options moderate trust between the architect and WHITE BRIDGE to mitigate analytical and logical weaknesses (Wang et al., 2019). The ‘Confidence of the system’ (see Figure 4, upper left) in the own classification of the drawn sketch is displayed as a colour-coded loading circle, which can be further investigated through a drop down window. The system communicates the recognition of rooms in the sketch through colour and hatches as an indicator of the room type (e.g. ‘wood flooring’ for a 'bedroom') (see Figure 5, left). Finally, the original floor plans (see Figure 5, right) for generating the displayed suggestion, can be accessed in a second step (see Figure 2: 'More Details' of 'Building context information').

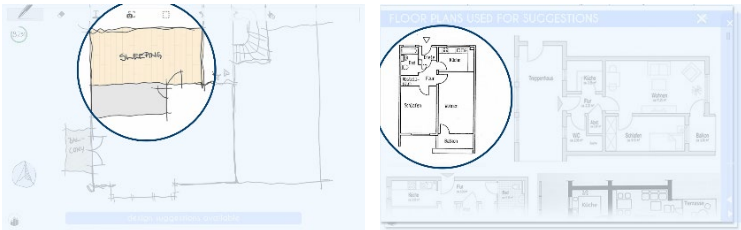

Figure 5. Highlighted explanation visualisation for moderating trust.

5. Case Study

The described interactive high-fidelity prototype was created for a case study with domain experts. Due to the current Covid-19 pandemic it was decided to conduct the study remotely ensuring the health of researcher and participants. In order to overcome possible hindrances of the remote study, such as bad internet connectivity, bugs within the prototype, or focus on the unfamiliar hypothetical application (instead of the explanation visualisations), the architects received preparatory material beforehand, i.e. instructions, a narrated and choreographed video presentation of the digital prototype, and an introduction to WHITE BRIDGE. The latter text was devised as narrated storytelling for near-future concepts to speak to the reader's emotions and personal memories, while leaving room for ambiguity (Spaulding and Faste, 2013). An imaginary persona describes the own experiences with the hypothetical application WHITE BRIDGE, while addressing possible fears and suspicions, and its modus operandi, illustrated with a photo collage of the application in an everyday setting.

After two test sessions with volunteers, eleven participants of diverse background (e.g. Europe, North Africa, South-East Asia, Middle East), aged between 25 and 35 years and working in Central Europe (i.e. Germany, Switzerland, France and Italy), were recruited for the study with individually scheduled sessions held in German or English. After autonomously reading the introductory text to WHITE BRIDGE, the joint sessions consisted of the narrated video presentation of the paper prototype and a semi-structured interview with three question sections: explanations, explanation visualisations and user perception.

The data analysis consists of three stages (see Figure 6): primary data, secondary data and processed data. The primary data of the video recordings was asynchronously transcribed, revised, and divided by speaker and further by question section. The textual results of each questions section were fed into an algorithm to create word clouds for visualising the participants' words and their frequency in an attempt to adjust the interpretation of the researcher with prior domain knowledge. Simultaneously, the answers of the participants were extracted, and revised on the backdrop of the participants' expressions if and how users were supported, trust between system and user was moderated and/or biases were successfully mitigated. A conformed terminology was used to re-sort all resulting tables by answer for each question. These tables were further processed through interpretation in one mind map per question section. Both the mind maps and the word clouds are further interpreted by the researcher for formulating and formalising the findings of the study.

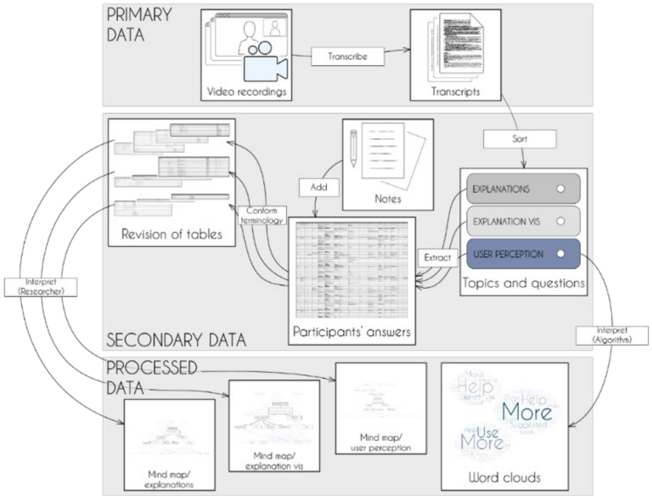

Figure 6. Workflow of the data analysis.

6. Discussion

The findings of the study indicate a broadening of the cognitive horizon of the participants through the explanations and their respective visualisations. During the sessions explanation methods were applied by the architects as intended, as well as for other purposes depending on the application method. For example, the multitude of suggestions for supporting the AHP through comparison was used instead for mitigating the confirmation bias through self-validation. Thus, greater design decision support than expected could be achieved. Especially information of the 'next step' (Participants 3, 6), e.g. the daylight simulation, was deemed highly useful, while the visibility of information for decisions beyond the current phase was rather irritating for most users (Lawson, 2004, p. 53), e.g. 'Material' of 'Building context information'.

The whole concept, explanation visualisations and the experience concerning the explanations, their own design decision and the hypothetical application of WHITE BRIDGE were widely positively received by the participants. One architect, even though recognising possible opportunities, expressed increasing mistrust and insecurity due to deprived ownership over their own design process. Most participants wished only for minor adjustments for working even faster and some even expressed the desire to use the hypothetical application in real life (Participant 4, 11). Summarising, the explanations used within WHITE BRIDGE expanded the cognitive limits of all participants within the study, even in unanticipated ways. However, if the information did not seem useful (see above) it may irritate the architect. To conclude, the usability of explanations is significantly influenced by their visualisations for the visually driven target group. Consequently, the perception of the explanation visualisations, positive or negative, can affect the perception of the entire application correspondingly.

Nevertheless, these findings of the conducted study need to be viewed on the backdrop of its limited number and diversity among the participants, who are of roughly the same age, work experience (i.e. duration and digital tools) and education, and personally affiliated with the study supervisor. Thus, this study can only be considered a pilot study without true scientific significance. Further, the study was conducted remotely suggesting that the entirety of the body language of the participants (i.e. gestures, mimic) could not be observed.

7. Conclusion

The results suggest that the cognitive horizon of the architects is broadened by the explanations, while the visualisation methods significantly influence the usefulness and use of the conveyed information within the explanations. Architects are supported and themselves identify opportunities in working with an intelligent design assistant, while a sense of control and ownership over design decisions is given. Individual design decisions can be made more quickly and confidently, speeding up the entire architectural design process. Expressed relief by the study participants suggests that the intelligent design assistant also contributes to reducing the architect's stress and mental strain caused by the increasing challenges and workload of the future.

By adapting the framework of Wang et al. (2019) through following their provided steps, the created explainability methods are suitable for an intelligent design assistant to support architects in their design-decision making processes. This paper contributes an established workflow adapted for the domain of architecture for the integration of explanation visualisations in paper prototypes for case studies, the preparation of the study participants, and the data collection and analysis process. Thus, it offers an approach for designing and visualising explainability of an intelligent design assistant for architects, suggesting further design steps during the early design stages. Further, it is transferable to different domains of the construction industry as well as other fields.

In order to determine the right time for the explanation visualisations, we aim to integrate the findings of our sketch study analysing the design process on the backdrop of the design phases (Lawson, 2004; Laseau, 2000), described within our papers of CAADRIA 2022 and ICCC 2022. By utilising these findings, we are enabled to determine the timing for the suggestions and their respective explanation visualisations to avoid answering to future questions or implying "that more is known about the solution than is really the case" (Lawson, 2004, p. 53).

As mentioned in the beginning, quick, efficient and sustainable work is essential for meeting the future demands on the construction industry, while shaping both space on a micro-scale in apartments and on a macro-scale of the urban space. The hypothetical intelligent design assistant WHITE BRIDGE aims to support architects in their design decision making process of the early design stages through suggestions, enriched with explanations. The intelligent design assistant intends to help architects to meet the increasing demand of high-quality architecture, while enabling architects to focus on the creative aspects of the design process. Finally, we hope that our work may inspire and guide future research for supporting architects in designing with confidence and in more informed ways early on to create high quality architecture more efficiently and more sustainably.

Acknowledgements

We want to thank the participants of the study for their time and valuable feedback, as well as the DFG for funding the 'metis' projects.

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