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The Assessment of Building Energy Functionality in the Integrated Building Design †

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Abstract: Buildings are significant contributors to energy-related sustainability challenges and a sustainable future. Practice shows—that the traditional building design process is becoming ineffective and will no longer be able to meet the determined requirements and standards of low energy architecture. The aim of this research is to introduce and validate the newly developed technology of building design concept, which integrates Quality Function Deployment (QFD) and Axiomatic Design (AD) methods. The proposed technology eliminates the traditional building design problems, ensures a smooth Integrated Building Design (IBD) process and matches the needs of the customer and the whole building design team. The new technology also provides a quicker and more effective way to find a sustainable and customer-orientated solution. Validation of the technology on the case study has shown that the energy functionality of the building proved to be superior to buildings, created during traditional building design process.

Keywords: efficiency; Integrated Building Design; BIM; Quality Function Deployment; Axiomatic Design

1. Introduction

The built environment provides low-cost and short-term opportunities to reduce emissions, first and foremost through improving of the energy performance of buildings. It is estimated, that emissions in this area could be reduced by around 90% by 2050 [1]. Meanwhile, the Efficient World Scenario highlights the potential for global building energy demand to decline nearly 40% between now and 2040, despite the total building floor area growing by a further 60% [2].

The building design community is challenged by the continuously increasing energy demands that are often in conjunction with ambitious goals for the indoor environment. In addition to stricter energy demands, the use of environmental assessment methods has increased considerably [3]. It is, therefore, necessary to change the contemporary architectural building design process and the role of the participants involved. In the traditional architectural design process, the multiple professionals have minimum interaction along a rather sequential process. Furthermore, the following issues often occur: architectural-design solutions are often orientated only one-sidedly, for example—to achieve a good aesthetic view, some possible architectural variations, in order to fulfil customers' needs—are changed intuitively, based only on the experience of the architect. Therefore, the listed issues lead to the fact, that the technical systems and their capacities have to be selected according to the adopted architectural solutions, which increases systems capacities, investments and, predispose inefficiencies [4].

The aim of this research is to introduce and validate a newly developed technology of building design concept. The application of Quality Function Deployment (QFD) and Axiomatic Design (AD) methods are rare in construction and have never been used in the Integrated Building Design (IBD) process, but their integration here seems promising. The exceptional features of these methods help

to eliminate many drawbacks of traditional building design processes as well as to determine, combine and fulfil the initial needs of the IBD team. The technology employs digital design and modelling tools, together with Life Cycle Analysis (LCA), which enables to create and check the efficiency and level of sustainability of design solutions in the early stage of the project. The newly developed technology ensures more quicker and more effective way to find a sustainable and customer-orientated solution.

2. Materials and Methods

Quality Function Deployment (QFD) and Axiomatic Design (AD) methods, which are widely known in common engineering, have been integrated into the new proposed technology of building design concept. Thus far they have never been used in the IBD process. QFD helps to identify and match the needs of the customer and design team, while AD—helps to ensure the realisation. Also, the multi-criteria decision making method COPRAS (Complex Proportional Assessment) and Life Cycle Analysis are provided in the technology as complementary steps. To demonstrate the validity of the technology, the systematic and case study analysis have been used. The digital architectural building model has been created using Revit, and the energy modelling was performed with DesignBuilder. The proposed technology (Figure 1) contains of six main steps: (1) analysis of initial data, (2) the determination/compatibility of customers and IBD team needs (QFD), (3) creating the theoretical building design concept (AD), (4) determination of criteria values, (5) decision making and (6) detailed design process. Customer, architect and IBD team cooperation starts from the early design stage of the building. The design facilitator (Building Information Modeling (BIM) manager) here is offered to assist and prepare the information for different groups.

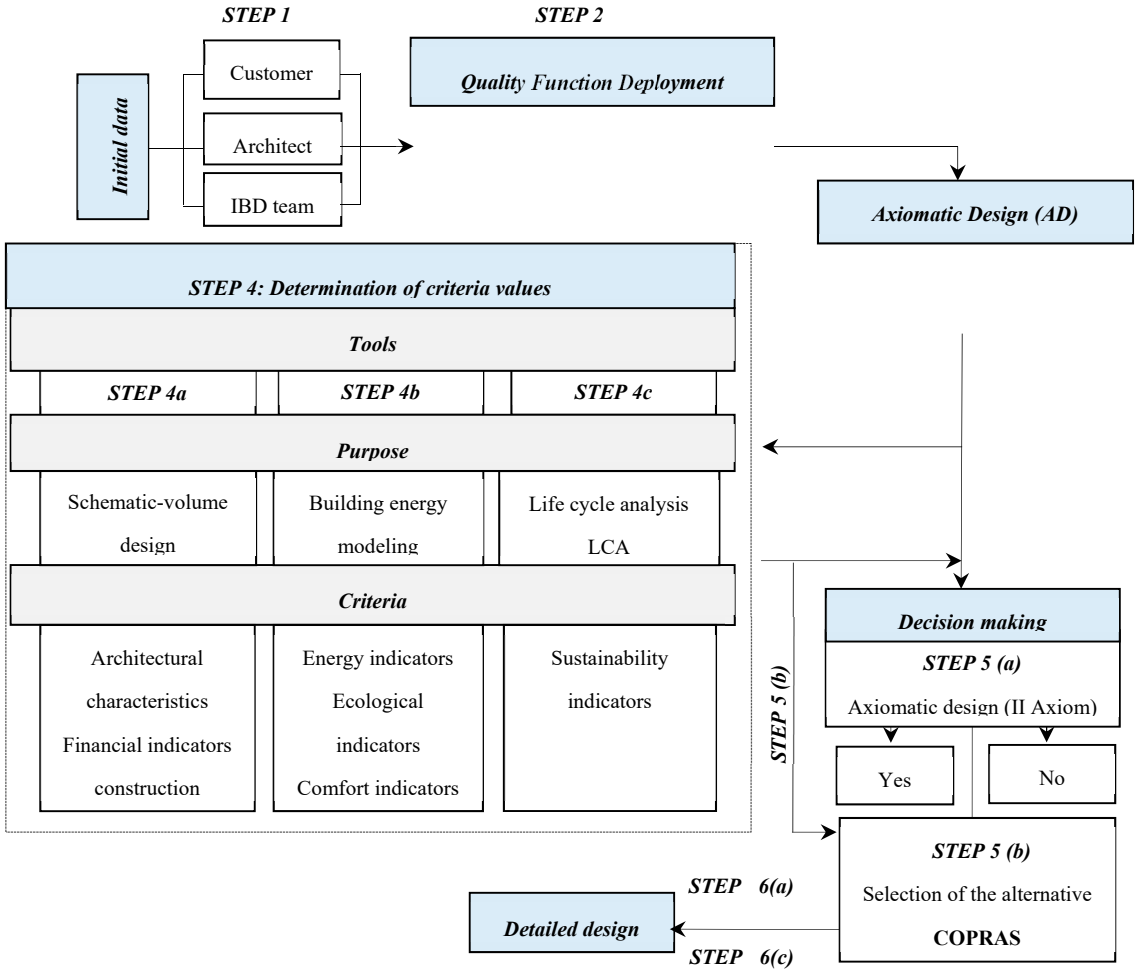

Figure 1. The technology of the architectural design concept.

The developed technology of building design concept has been validated, setting the building envelope energy functionality for the case study using two design processes: traditional and based on the technology. Minimal building energy consumption was set for the case study as the most important requirement to be satisfied. The designed buildings were compared, seeking to define, which of them better fulfilled the main requirement.

3. Results

The results have shown that integration of QFD and AD in the technology helped to purify and match the initial requirements of the project and to create the hierarchical schemes of functional requirements and design parameters. Mapping through the domains (see Figure 2), the initial needs were transformed into the functional requirements (what to reach?) and the design parameters (how to reach?)—were generated with purpose of fulfilling the functional requirements.

The application of these specified design parameters helped the architect to create the building design concept, that was purpose-oriented to minimise building energy consumption (see Figure 3a).

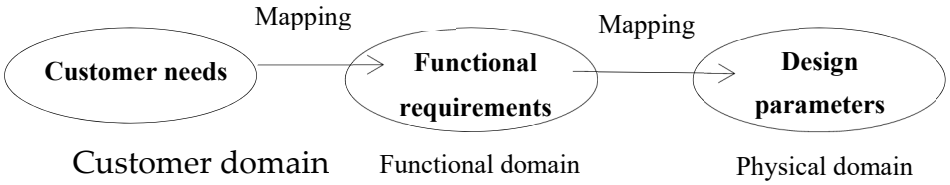

Figure 2. Mapping between the domains.

Following the traditional building design process—the second building concept alternative was created only based only the architecture's experience (Figure 3b).

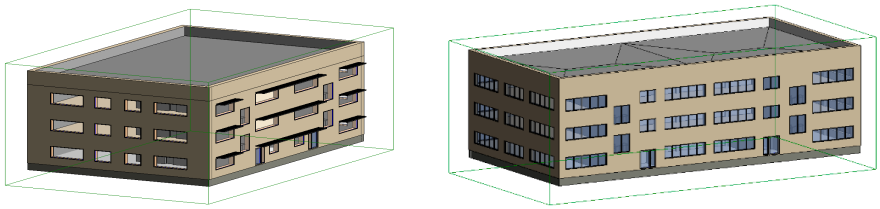

Figure 3. Building concept alternatives (**a**) based on technology; and (**b**) traditional design.

Both building design concepts have been simulated in DesignBuilder and compared setting the parameters of building energy functionality: energy consumption for heating, cooling, lighting, auxiliary energy and primary energy (PE) (Table 1).

Table 1 shows the difference between the effectiveness of the energy functionality of the building alternatives, that were created during two different design processes. The results of the case study have shown that the main functional requirement—to minimise energy consumption—using the proposed technology, was fulfilled more efficiently.

Table 1. The parameters of buildings energy functionality.

Energy Demand	Technology Based	Traditional	The Strength (+)/Weakness (–) of the Proposed Technology
Heating, kWh/m²	4, 6	14, 3	>100%
Cooling, kWh/m²	8, 9	11, 8	24%
Lighting, kWh/m²	11, 7	6, 6	−77%
Aux. energy, kWh/m²	9, 0	10, 9	17%
PE, kWh/m²	88, 0	98, 0	11%

4. Discussion and Conclusions

The strengthen requirements for the construction industry has lead to the fact, that the building design process should be based on energy efficiency, sustainability, etc. The building design process becomes complex and faces many challenges, due to the many participants involved, the different and often conflicting requirements that have to be fulfilled, and the increasing size of the projects.

This paper presents the newly developed technology of the building design concept, which integrated in common engineering known design methods, digital design and modelling tools and the principles of IBD.

Validation of the proposed technology has shown, that following it, it becomes easier and quicker to reach the main project goals. The IBD process concentrates the whole design team and enables them to focus their interests at the beginning of the project. Nevertheless, this does not ensure, that all the determined requirements will be fulfilled. Seeking to maximise the effectiveness of this process the new developed technology of building concept integrated QFD and AD methods, which helped to create the hierarchical schemes of functional requirements and design parameters for all of them. The building design concept was composed and modelled according to these parameters. The modern design/analysis/modelling tools facilitate the building design process and provide an opportunity for checking the efficiency and sustainability of the design solutions in the early stage of building design, when any design corrections are still available.

The developed technology of building design concept has been validated, setting the building envelope energy functionality for the case study using two design processes: traditional and based on the technology. The results have shown, that almost all of the parameters of building energy functionality based on technology proved to be superior against the building, created during the traditional building design process. Here the energy consumption for heating was almost three times less; and for cooling—24% less, Auxiliary energy was 17% less and PE was 11% less.

Author Contributions: V.L. developed the new technology of building design concept, contributed the materials/analysis. V.M. made the energy modelling. A.R. wrote the paper.

Conflicts of Interest: The authors declare no conflict of interest.

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