Facilitating Environmental Performance Assessment in Architectural Design Competitions utilizing a Model-based Workflow

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ABSTRACT: We present a novel approach for facilitating fast but comprehensive energy and exergy performance assessment in architectural design competitions utilizing building information modeling and an iterative workflow based on a customized software framework. The approach is exemplified with all seven invited participating offices of an actual design competition for a zero emission high-rise building in Zurich, Switzerland. In addition to the assessment of environmental performance, the BIM was used for evaluation of spatial economy and quantity takeoff of the final competition designs, thus providing a richer database for decision making.

1 INTRODUCTION

Recognizing the impact of buildings on global energy consumption and CO₂ emissions worldwide as stated by the IPCC (Levine, Ürge-Vorsatz et al. 2007), their environmental performance has become of increasing importance. This awareness has lead to environmental performance of a building being a marketable value. In order to be most effective, it is widely acknowledged that this has to be considered already in the early design stages.

In many countries, design competitions are required for new public buildings of building retrofits over a certain size. Also for private buildings of importance, design competitions between architecture offices are used to find the best solutions. In Switzerland, the environmental performance of an architectural design has become standard criterion in the evaluation process, its assessment a deliverable for the architect. Based on the standards to be applied, a variety of tools is offered to calculate environmental parameters during the competition phase. Such tools are mostly based on spreadsheets where key parameters of the building (area, envelope properties etc.) have to be manually entered and as a result a range of key performance indices is calculated. As this process is tedious, time-consuming and non-iterative, this is mostly done after the actual design, after all design decisions are already made. As geometry, material and systems data is not directly linked to the actual building design, inaccuracy or differences in numbers can easily happen and are hard to be recognized.

For architects such a procedure is unfavorable, as it is not integrated in the iterative and intuitive design process. Additionally, as the bi-directional link is missing, the impact of environmental parameters on the building design is not reflected. This leads to the common notion of environmental criteria being an obstruction to the design process rather than enrichment.

In this work we present an approach on how to integrate environmental performance assessment into an architectural design competition process, allowing for a bi-directional link between design and building performance criteria. Digital modeling is used to generate, store and communicate the crucial information, to drive performance simulation and provide relevant quantity takeoffs.

Prior to the employment in the design competition, the model-based process and toolset were utilized for the development of energy-efficient retrofit scenarios (Schlueter and Thesseling 2008), early stage design development (Thesseling and Schlueter 2008) and for the integrated design of prefabricated façade modules (Schlueter 2011).

1.1 Competition Project

The objective of the invited design competition was a mixed-use high-rise building of 50,000 m² near Zurich, at a central location of a newly designed and partially already realized city quarter.

A strong commitment to sustainability, especially to the objective of minimizing CO₂-emissions, led the project developer to require comprehensive performance assessment already during the competition...
phase. However, for this process to be accepted by the invited design teams (all of the competitors were highly regarded Swiss architectural offices) it was important that the assessment is fast, requires only minimum additional input and can seamlessly be integrated into the architectural design process. These requirements permitted extensive and time-consuming applications outside of the design environment.

Besides the standard competition requirements concerning functions, spatial program, urban and architectural design, the requirements related to environmental performance were demanding, as the objective was to reach zero emissions in operation. The employment of LowEx building systems (Leibundgut 2011) was recommended, including low temperature district heating / high temperature district cooling using waste water as a heat source in combination with efficient heat pumps. For the ventilation, decentralized ventilation units were to be placed at the facade, requiring less space for ducting and less energy due to smaller pressure losses (Baldini and Meggers 2008). For efficient heat/cold distribution, radiant floor heating was to be employed. For the building envelope, specified heat transfer coefficients had to be reached to ensure thermal comfort and to fulfill local building regulations.

1.2 Performance Assessment workflow

To make design performance assessment equally accessible for every participating office, independently of in-house competences and software, a performance assessment toolkit, the Design Performance Viewer (DPV) (see section 3.1) was provided. It is based on a building information modeling (BIM) platform. It was open to the participating offices if they establish the model themselves and use the supplied toolset or if they collaborate with an external specialist for modeling and simulation. During the competition phase, every office was offered two workshops with the external consultant to evaluate the existing design state in terms of environmental performance and to discuss implications and measures to improve (Fig.1).

As a competition deliverable, each team had to hand in the building information model for the final performance assessment and for the quantity takeoff of relevant floor spaces and volumes. Both were reported to the project developer and the competition jury.

2 BUILDING MODELLING

A crucial and novel step during the competition phase was to ask the architecture offices to establish and maintain a building information model containing not only geometry data but also location / orientation, material/construction and technical systems data. To avoid this being a reason for not taking part in the competition, help in establishing and maintaining the model was offered to each team. In case the offices would not create an own BIM, the alternative was to use 3D digital design models and extend them to entail the necessary information to run the performance assessment.

2.1.1 Location and Climate

Information on the site-specific climate was added to the BIM using the localization feature of the DPV, linking geographical information with the corresponding climate data. For Switzerland, this data is provided by the SIA (SIA e.V. 2008) to be used in the relevant calculations. The building orientation, responsible for solar irradiation on the building surfaces, is defined in the BIM modeler interface. This information is considered by the DPV for the performance calculations.

2.1.2 Geometry

All participating offices used the design-modeling environment they were accustomed to for the development of the geometry and relevant building elements such as floors, windows, columns and walls. At dedicated steps, the design model geometry was transferred to the building information modeling environment using 2D or 3D CAD formats. Test using the Industry Foundation Classes (IFC) (buildingSmart 2007) for data exchange proved to be highly dependent on the quality of export of the different design modeling tools. For the BIM, only the elements necessary for the simulations and quantity takeoffs were included, such as envelope elements of the envelope or objects of relevant thermal mass. Templates and automated parameterization were used to minimize additional manual input of parameters.

2.1.3 Material / Construction

As materialization is crucial not only for architectural design but also for environmental performance, material properties such as density, specific heat capacity, thermal resistance, solar heat gain coeffi-

Fig.1 Iterative Competition w/ with Performance Assessment
2.1.4 Technical Building Systems
The issue of missing knowledge and detail during the early design stages also applies to the technical systems for the supply of heat, cold and electricity. To encounter this, the DPV provides abstract technical systems to be defined as objects of the building information model. Addressed are the source, generation, distribution and emission of heat and cold as well as the generation of electricity using solar energy. At the beginning of the design the abstract systems can be generically defined and refined as the design progresses and more information on the envelope as well as on sources and their temperatures are available (Schlueter and Thesseling 2008) (Fig 2).

3 DESIGN PERFORMANCE ASSESSMENT

After the initial establishment, the Building Information Model was used for continuous energy and exergy performance assessment at dedicated steps throughout the competition, enabling the participating architects to consider energy, exergy and related CO₂-emissions as parameters in design.

3.1 Design Performance Viewer

The DPV is embedded into the building information modeling software Revit (Autodesk Inc. 2008). It utilizes the internal BIM for the extraction of relevant building information tailored to the simulation task. After simulation, the results are fed back into the model and instantly visualized using different diagrams (Fig.3). Due to the embedding into the BIM software, which also may serve as the design environment for the architect, performance feedback is available within seconds. A history function records the model states and state-related performance. By comparing different model states, changes in performance due to changes in geometry, construction, materials or systems are rapidly visualized. Due to the bidirectional link, not only the entire building model but also the model history and related performance information is part of the model and can be exchanged to collaborators.

3.2 Metrics for Energy, Exergy and Emissions

The DVP employs a range of calculation models for performance assessment. As the competition designs hat to comply with the Swiss building regulations, the model for calculating the monthly heating energy demand provided by the SIA 380.1 was used. The model provides standard occupations of space containing averaged values for internal gains by people, lighting and electrical appliances as well as air exchange rates and interior temperatures. The key metrics of the SIA 380.1 model are the annual / monthly heating energy demand, transmission heat losses through the envelope (wall, floor, window, roof), ventilation heat losses and gains (solar, people appliances).
The energy model was combined with an exergy / emissions calculation model developed as part of the IEA Annex 49 (IEA Annex 49 2011). It provides an exergy calculation over the heating chain, considering the efficiencies of chosen systems and the resulting demand of high-potential energy (exergy), such as provided by electricity, and low-potential energy (anergy) that can be acquired from the environment, for example by using geothermal heat (Meggers and Leibundgut 2009) or in this case district heat. The key metrics are the efficiency of the heat / cold generation (COP), the exergy demand for heating and electricity usage and the resulting CO₂ emissions according to the chosen energy source.

3.3 Metrics for Spatial Economy and Quantity Takeoffs

For the categorization and quantification of the different floor spaces of the competition designs the Swiss norm SIA 416 was used. Specified metrics to assess spatial economy were provided by the project developer itself. The areas of the different floor spaces and the volumes above and below ground were taken directly from the final BIM. To be compliant to the definitions of the SIA 416, the areas defined in the BIM by using room boundaries had to be manually refined.

For the quantity takeoff, exterior wall surfaces, surfaces below ground, fenestration and roof surfaces were directly assessed and aggregated from the BIM using the reporting functionality of the DPV as well as custom quantity schedules in the BIM modeling environment.

4 RESULTS

Two novelties were introduced into architectural design competitions in Switzerland. First, the establishment, maintenance and delivery of a Building Information Model from the very beginning of the design and second, the iterative and integrated environmental and spatial performance assessment utilizing the model throughout the process. In the following section, the competition results in terms of process, modeling and performance are outlined1.

4.1 Integrated Design Process

For the establishment and maintaining of the BIM as well as for the performance assessment, each of the offices that took part in the competition decided to involve the external consultant. On two occasions during the competition phase, the BIM was matched with the current design state using the 2D/3D design drawings and text documents provided by the offices. Using the two workshops, the environmental performance was assessed and discussed, using the DPV. Alternative solutions were collaboratively explored in real time by changing parameters in the BIM and running the simulation. The instant changes in performance due to changes in geometry, material, construction and systems helped to raise the understanding of the interdependencies and impact of the various parameters.

4.2 Energy Performance

As the building systems were already well defined by the competition program and the internal loads defined by the regulations, differences in the energy / exergy performance was mainly related to the geometry of opaque and transparent surfaces and the materialization of the building envelope. This was assessed using the final BIM and reported as a key performance index. Using the two workshops for it-

1 The competition designs are anonymized.
The bandwidth of annual heating energy demand of the competition designs was between 59 kWh/m2a and 101 kWh/m2a. The difference in results was mainly caused by different opening ratios and constructions of the building envelope, which is indicated by comparing envelope heat losses with solar heat gains.

As the energy supply of the building will be using emission-free energy sources, it was not necessary to absolutely minimize the heating energy demand as higher losses can be counterbalanced without causing additional CO₂ emissions. Also, thermal performance of the envelope was not supposed to be a constraining factor for architectural design expression. It was therefore open to the offices to weight the different influences on environmental performance in accordance to their design concept.

Employing the district heating network as a heat / cold source for the heat pump, no fossil fuels are necessary for heating and cooling of the future building. To reach a high thermal performance, the heat losses of the building have to be balanced with the supply temperature of the low temperature heating system. As this supply temperature was given and the heat losses of the building were rather small, each team was able to reach a high Coefficient of Performance (COP) of the heat pump, thus drastically diminishing the amount of electricity necessary for heating and cooling. If the electricity for the building is supplied from renewable sources, the building is emitting no emissions in operation.

The iterative model-based workflow led to good environmental performance of all the designs. To validate the environmental analysis, external experts additionally examined the final results after competition phase.

4.3 Spatial economy and quantity takeoff

After the end of the competition phase the final building information models were used for assessment of the different spatial typologies (Fig.6).

The relevant spatial typologies were extracted directly from the Building Information Model by using custom schedules in the BIM modeling environment and built-in quantity takeoff features. This data was collected and used for the final competition report, comparing the spatial economy of the different competition designs.

The building information model of the winning project will be further established in the detailed design stage. The aim is to utilize the model as a design information repository throughout the entire design, documentation and construction phase and up to the operational phase.

5 CONCLUSION

Although the first application of BIM-based performance assessment during an actual design competition was successful, there is still a lot of room for improvement.

As the building information model was not established nor maintained by the participating offices but by the external consultant, the actual design states were only transferred and assessed two times during the entire competition. A significant amount of time was needed to match the 2D/3D design drawings with the building information model to perform environmental performance assessment. This also meant that the model as an information repository could not be exchanged. The results and parameters had to be delivered during the workshops using additional text documents.

However, as the model-based workflow was integrated into the competition design process this was accepted by the contributing architectural offices and even considered beneficial, contrasting the notion of environmental criteria limiting creativity, as this is how many designers perceive it. If the offices would already use contemporary building infor-
mation modeling tools this process could have even been more seamless.

As stated by the project developer, the applied model–based process was beneficial for the fast evaluation and validation of environmental requirements and for comparison of key performance indices. Additionally, the time necessary to manually extract the relevant quantities out of the design documentation was minimized, reducing the overall costs of a design competition. Also for the delivery of the final reports a significant amount of time was necessary to match the final design data in terms of object and space definitions. This could be improved by providing a more specific information delivery manual.

The initial setup of LowEx building supply systems was a prerequisite for the competition, therefore already ensuring environmentally sound boundary conditions. The environmental building performance as assessed with the DPV rather used for validation and positioning of the different building designs. Of greater importance for the project developer were the key figures on spatial economy, also drawn from the final BIM. In fact, not the project with the best environmental performance but the best spatial performance in terms of functional mix and economy of space was selected as the winning project, together with architectural and urban design considerations.

For the developer, the results were convincing enough to employ an improved workflow, based on the findings of this case study, already in a new design competition. For more detailed building performance assessment including the dynamics of systems and environment, the current version of the DPV employs EnergyPlus (U.S. DOE 2008) as a fully integrated, dynamic simulation kernel.

We hope that exploring and demonstrating the benefits of building information modeling and integrated performance assessment during architectural design competitions helps spreading these technologies and methods. Not only for the progression of the building industry but also to design and built buildings that reach highest architectural and environmental standards.

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REFERENCES


