BIM

Integrative

Parametric

Performance

Sustainability

Balancing Design and Performance in Building Retrofitting

A Case Study Based on Parametric Modeling

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RETROFITTING THE EXISTING BUILDING STOCK WILL BECOME ONE OF THE KEY FIELDS OF ACTION FOR ARCHITECTS IN THE FUTURE. **Due to the raised awareness of CO_2 emissions related to the energy consumption of buildings, architects have to increasingly consider parameters influencing the energy performance of their retrofit designs. This is a complex task especially in the early design stages as multiple dependencies between building form, construction and technical systems influence overall energy performance. The inability to cope with this complexity often leads to simple solutions such as the application of massive insulation on the outside, neglecting aesthetic expression and design flexibility. Digital models storing multidisciplinary building information make it possible to include performance parameters throughout the architectural design process. In addition to the geometric parameters constituting the form, semantic and topological parameters define building element properties and their dependencies. This offers an integrated view of the building. We present a case study utilizing mulit-parametric façade elements within a building information model for an integrated design approach. The case study is based on a retrofit project of a multi-family house with very poor energy performance. Within a design workshop a parametric building model was used for the development of the designs. An integrated analysis tool allowed an immediate performance assessment without importing or exporting building data. The students were able to freely define geometric and performance parameters to develop their design solution. Balancing between formal expression and energy performance lead to integrated design sketches, resulting in surprising solutions for the given design task.**

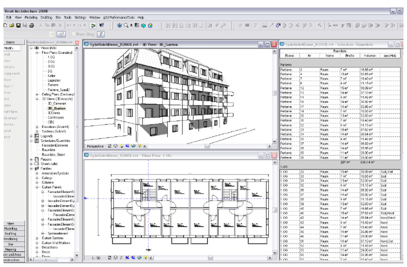


FIGURE 1. EXISTING BUILDING, FLOORPLAN

FIGURE 2. BIM OF THE EXISTING BUILDING

1 Introduction

In European countries, the retrofitting and renovation of the existing building stock will become the key area of work for architects as the amount of building retrofits increases continuously (BBR 2007). Today's main drivers for retrofitting are environmental issues. Due to the raised worldwide awareness of CO_2 emissions related to energy consumption of buildings, architects have to increasingly consider parameters influencing the energy performance of their retrofit designs. The traditional view on how to cope with environmental issues in buildings is still often very limited. In this view, the energy performance of buildings is considered *in opposition* to the freedom of aesthetic expression. Other realized examples of building focusing on energy performance denote the other extreme, promoting excessive formal and material measures to achieve sufficient building energy performance.

The current architectural design process lacks the necessary integrated view of the building. Due to the complexity arising from multiple dependencies between form, material and technical systems, an integrated view of the building can only be achieved by utilizing computational tools and methods (Brahme 2001). The method of building information modeling resembles one recent approach to capture these manifold dependencies by adding parameters to define the building components more closely. Geometric, topological as well as semantic parameters are stored within the building model which therefore acts as a data repository (Eastman 1999). The neglecting of the multiple dependencies between form, material and technical systems often leads to simplified answers such as applying massive insulation layers on the building envelope. Due to conservation constraints and unsatisfying visual appearance this is often not suitable for retrofitting purposes. No tools are available to support an integrated view on a building design from the important early design stage on. Tools analyzing energy consumption and other environmental criteria such as simulation software are mostly applied after the design stage, thus not influencing design decisions made during the early design stages.

We present an approach utilizing parametric facade components to develop integrated design sketches. Multidisciplinary criteria such as geometry, topology and physical performance parameters are used to define the designs, considering form and energy performance as equal stakeholders in the design process. An especially developed tool utilizes the information stored in the building information model to execute real-time energy performance calculations. Within a conceptual workshop, students explored the capabilities of parametric design, working with a building information model from the beginning of the design on.

1.1 RETROFIT DESIGN TASK

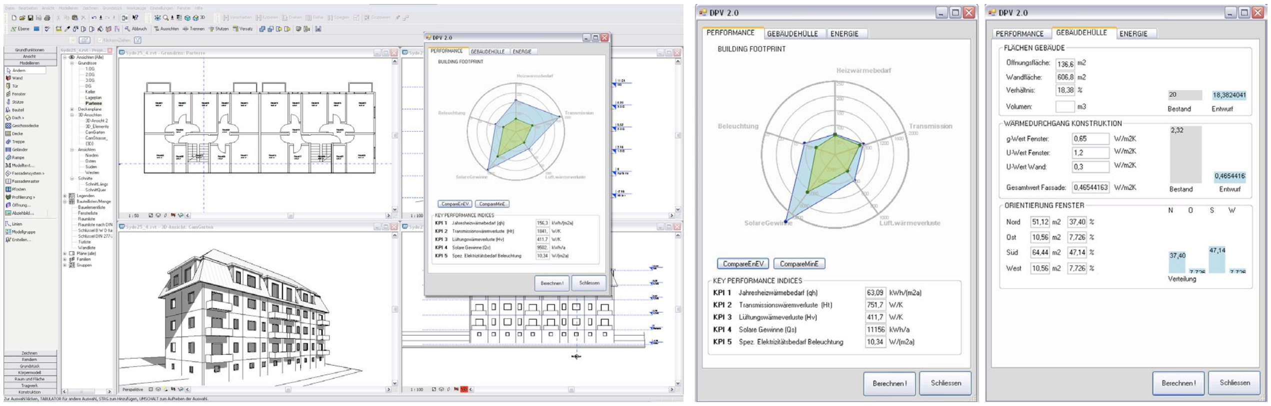
The design task for the students workshop was the retrofitting of an multi-family house in Zurich, Switzerland, built in 1931 (Figure 1). The age and condition of the building is exemplary for many buildings in Zurich. Built with simple, massive walls without any insulation, its primary energy consumption is excessive. 21.000 liters of oil are required for the heating and domestic hot water per year. Obviously, there is a huge potential to increase the energy performance.

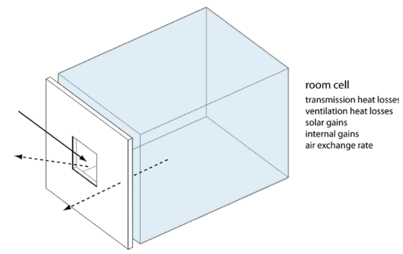
Due to the building owner, a non-profit organization for affordable housing, concepts for the retrofitting had to consider the aesthetic expression of the façade as well as the economic impacts of retrofitting measures. Within the one-week design workshop, students were asked to redesign the facade as the most important interface between architecture and energy performance. After discussing and developing the concept of the technical infrastructure inside of the building, the students were asked to develop an architectural concept. In their approaches they were asked to consider performance parameters equally to geometric/aesthetic parameters, to balance measures of form, construction/material and technical infrastructure systems.

2 Methods

2.1 RETROFITTING FOR CO_2-FREE BUILDING OPERATION

The concepts for the technical infrastructure for heating, ventilation and lighting were laid-





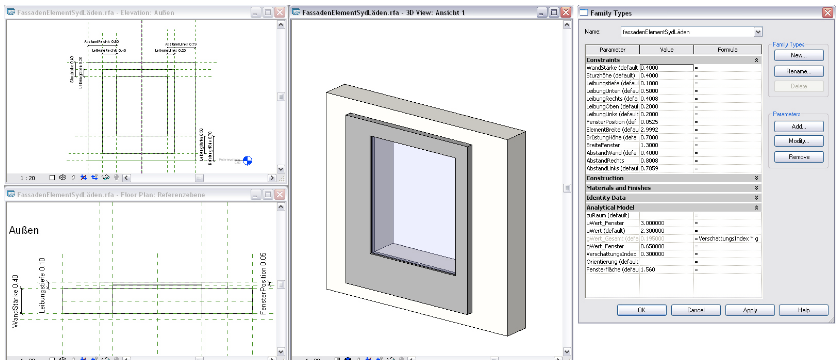


FIGURE 3. ROOM CELL TOPOLOGY

FIGURE 4. BUILDING MODEL WITH INTEGRATED DPV, INTERFACES

FIGURE 5. GROUP 1, PARAMETRIC FAÇADE ELEMENT

out at the beginning of the workshop by developing schematic sketches of the infrastructure systems. The aim was the CO_2-free operation of the building, not permitting the burning of fossil fuels inside. The existing oil burner was supposed to be replaced by an efficient heat pump, utilizing the potential of the heat stored in the ground for the generation of heating energy. Due to the efficiency of the thermodynamic process of the heat pump being highly dependent on the heating systems inlet temperature, the overall heating system has to be designed to enable an inlet temperature as low as possible. The existing heat distribution system of pipes and the emission system of radiators were supposed to remain. Therefore, in order to run the heating with a low temperature of 28° C, the transmission heat losses of the envelope have to be low. Otherwise the small distribution area of the radiators would not be sufficient to cover the heat losses and thus to heat the rooms. Therefore, realizing an energy efficient, CO_2-free operation of a building is dependent on the layout of the technical systems but also on the energetic performance of the building envelope. The building envelope consists out of façade, roof and floor to ground. For the design workshop, the students were asked to focus on the façade as the most important interface between architecture and building performance.

2.2 PARAMETRIC BUILDING INFORMATION MODEL

The students were supplied with a building information model of the existing building (Figure 2). Within the modeling editor, they were able to edit and adapt the multidisciplinary parameters embedded. These parameters can be separated into geometric parameters describing building form, topological parameters capturing dependencies of building elements (e.g. window-wall-room) and semantic parameters integrating physical properties of building components and environmental context.

To apply the analytical model for performance assessment, the volume of the building was subdivided into room cells with cell surfaces to the inside (interior walls) and to the outside (walls facing the exterior) environment. This subdivision is reflected on the façade by individual façade elements that are related to a room cell. The façade element can contain openings that influence its ventilation and transmission heat losses, solar gains and the amount of daylight received (Figure 3). In the building model, each façade elements is

represented by an element family, containing all geometry and performance parameters. Physical properties such as thermal transmittance (u-value) of the opaque and transparent surfaces or the solar transmittance (g-value) of the transparent surfaces have to be set according to the chosen construction.

2.3 INTEGRATED PERFORMANCE ASSESSMENT—THE DESIGN PERFORMANCE VIEWER

For fast and easy performance assessment of the design from the early stage on, an integrated software tool was developed. The Design Performance Viewer (DPV) is used directly within the modeling environment, no export of building model data to a simulation software is necessary. The tool was realized as an add-on to the modeling software "REVIT" from Autodesk (Autodesk 2008), accessing the model database via the supplied API (Application Programming Interface). The building model within REVIT was extended to store physical properties but also topological dependencies of building components such as wall and windows. The implemented calculation model obtains all necessary data from the extended building information model, allowing performance calculations in quasi real time. Although not as detailed as expert tools using dynamic, physical simulations, the results are detailed enough to fulfill the regulations and, more important, to enable decision making within the design process. This allows a direct linkage between the performance and the progression of the design. Every change in design, for example of the building form, the size of openings or façade materialization results in changes of the energy performance, displayed in selected key performance indices. These indices are calculated in accordance to the requirements of the European Buildings Directive (Directive 2002) and cover the most important key figures related to energy consumption:

- Transmission heat losses
- Ventilation heat losses
- Annual heating energy demand
- Solar gains
- Internal gains
- Specific lighting energy demand

The mathematical model for the calculation is derived from the German Energy Conservation Regulation (EnEV 2007) and the Swiss regulations (SIA 2008). The calculation results are immediately graphically visualized using a kiviat graph, creating a characteristic footprint (Figure 4). This footprint allows fast and intuitive readability of the energy performance indices, especially for the architect who often is not experienced in interpreting large data tables. In addition, the geometric and physical properties of the whole façade are displayed. The ratio of open and closed surface areas of the façade is an important design criterion. Simple bar graphs allow the comparison to the existing building, showing tendencies and impact of retrofitting measures. Physical properties of envelope components such as windows and walls are displayed, an overall thermal transmittance of the façade takes different materializations of the façade elements into account. Again, a bar

FIGURE 6. FAÇADE GROUP 1

chart allows the comparison between the existing building and the current redesign proposal (Figure 4).

3 Results

The one week workshop was conducted with eleven students of architecture to explore different approaches when considering building form and energy performance as equal stakeholders in design. Supplied with the initial, extended BIM, they were asked to develop a new façade by designing parametric families. The students were free to chose as many individual families to realize their designs.. Openings, construction and materialization had to be defined, physical properties such as thermal conductivity of building materials had to be researched and added to the family parameters. When placed in the façade of the building model, the visual appearance could be checked. The DPV interface remained open during the design, every change in geometry or material could be calculated and was reflected in the performance indices. This resulted in an iterative design process, altering design parameters and viewing the results.

3.1 GROUP 1

The approach of this group is aimed at minimizing the effort for the retrofitting by achieving good performance results and a contemporary visual transformation of the façade. A window element was developed which contains shading components as well as decentralized mechanical ventilation, all integrated into the window-frame (Figure 5). Due to the geometric parameters, each individual frame can be configured to the elements' context in the façade. In addition to the window element, the group created a second element type containing a balcony which size and balustrade could also be altered.

The opaque façade was equipped with thermal insulation of 12 cm thickness and an insulation rendering of 7 cm. In combination with the original, about 35 cm thick massive walls, the window-frames reach a total depth of 54 cm, turning them into niches that could be added to the room space. After evaluating and calculating the thermal transmittance of different materializations of windows and façade, the design reached an annual heating energy demand of approximately 45 kWh/m2a. This is nearly one fourth of the annual heating energy demand of the existing building of approximately 165 kWh/m2a.

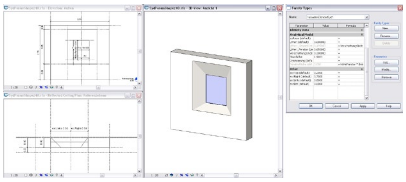
3.2 GROUP 2

The second group reinterpreted a common approach to lower the transmission heat losses of a façade. Often, the performance of a façade is increased by simply applying thick insulation onto the outside. This is economically favorable but visually unsatisfying. In the chosen approach, the thick insulation was used to modulate the façade by shaping the edges towards the openings. A parametric façade element was created to precisely control the inclination of the window soffits (Figure 7).

The resulting, three-dimensional façade elements react to the type of opening and the context of the rooms behind. This way, the monolithic but irregular façade elements creates a completely new visual appearance of the building. In a further design stage, the shaping of the openings could even be extended to react to the demand of daylight or solar radiation. Due to the thickness of the insulation an the high-quality windows the design reached an annual heating energy demand of approximately 55 kWh/m2a. The approach shows a simple, economic advantageous but effective solution to the task of achieving good energy performance and creating a new visual expression of the building. By altering only a small amount of parameters, the appearance of each element as well as of the whole façade can be greatly influenced.

3.3 GROUP 3

Instead of creating only one parametric façade element and adjusting its parameter values when placed into the façade, this group chose to create a whole set of different parametric families, each one specifically reacting on the location of the element within the façade (Figure 9). Comparable to the second group, the approach is based of utilizing the increased wall dimensions to modulate the façade not only in the x- and y-axis but also in the z-axis, using the thickness of the increased insulation to shape the formerly planar façade. In this case, the parametric families creates a wave pattern, oscillating differently on



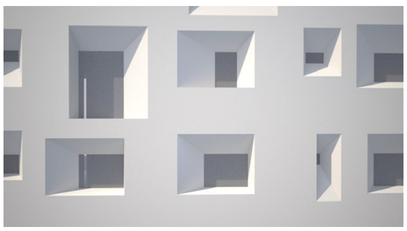


FIGURE 7. (TOP) GROUP 2, PARAMETRIC FAÇADE ELEMENTS

FIGURE 8. (MIDDLE & BOTTOM) FAÇADE GROUP 2

FIGURE 9. ELEMENTS AND FAÇADE GROUP 3

every level. The wave length and amplitude could be defined by changing the values of the specific families, also influencing the building performance as the increase or decrease of insulation was reflected in the analysis.

The resulting facades emphasize the linear structure of the building as each level is clearly shown. Although the elements can be defined to achieve a good overall energy performance, this approach, if realized, would pose challenges to avoid heat bridges as well as moisture problems. However, this approach displays very well how one parameters—the wave modulation—greatly influences the visual appearance as well as the energy performance.

4 Discussion

The modular setup of the facade derived from the analytical model proved to be very effective to explore the concept of parameterization. In order to design the façade, the students *had* to consider the parameters defining the single façade element. Resulting, the students had to create the set of rules defining the capabilities of their design. This change in process is probably the biggest difference to a conventional design approach. By iteratively developing their designs to satisfy both visual and performance criteria, both criteria were treated with the same attention. Unlike in a conventional design process, solutions of unsatisfying form or performance could be identified and changed earlier. Having to consider not only geometry but also physical properties made thinking about material and construction necessary, supporting a deeper understanding of the designs. The software setup of a rich BIM flanked by an real-time performance assessment tool proved to be capable of enabling these integrated design approaches. Considering the efforts necessary to retrofit the existing building stock to achieve better energy performance and reduce CO_2 emissions, such a setup could be highly useful to balance retrofitting measures.

However, software was still too big of an issue during the workshop. Although the editor is comparably easy to learn and the DPV designed to be easy to use, it took quite some effort for the students to understand the concept of parametric building information modeling. As the understanding of the concept is necessary to utilize the potential of such an approach, some students found it hard to adapt to a different strategy. Interestingly, the longer a student was involved with architectural design, the greater difficulties to adopt he or she was facing. Therefore there is a strong need to teach integrated design and the parameters, concepts and tools involved already early in architectural design education.

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