Teaching Building Envelope Design: A Project-Based Learning Method

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INTRODUCTION

In a traditional architectural education, technical knowledge is usually communicated in large-format lecture courses, frequently with a strong emphasis on science, math, and quantitative analysis. The sometimes abstract nature of the conveyed information can be difficult for students to retain, and can be even harder to integrate into design projects within a studio setting. Without a feasible application at hand, students tend to get frustrated with technical subjects and wonder about their usefulness and relevance in their education. Disinterest and lack of understanding of the subject matter are a direct result.

This is especially evident when students start to develop concepts for the building envelope, a sometimes unfamiliar and uncomfortable topic for them. Through personal experience, it is apparent that many students are unaware of the wide range of essential functions the envelope has to fulfill, and they therefore frequently misrepresent issues of enclosure in their design projects. This is partly due to the fact that the building envelope and its complex performance requirements combine aspects from all technical subjects: structure, environmental control systems, and architectural detailing. It seems like an insurmountable task for students to bring together all the required information from the various technical subjects, address them properly, and integrate them into a sound overall design for the envelope which, on top of everything, needs to fit the formal language of their building.

The building envelope's performance has a significant impact on the overall energy concept of a building. Professional practice and the general public have identified the need to further develop and build upon sustainable design principles. Especially in times when our natural resources are becoming limited, the architectural education in our schools should put an even stronger emphasis on teaching methods which will allow us to provide the next generation of architects with useful technical knowledge and design skills. In this context, the general need for a more systematic teaching approach with respect to a building's enclosure is apparent.

In an effort to address the problem at hand, this paper will examine new methods for teaching building envelope design. A course specifically developed for this purpose served as the testing ground for the application of innovative teaching ideas and has been outlined in the following.

COURSE SUMMARY

The building skin's primary task is to regulate the external climate conditions in order to provide comfortable internal conditions for the occupants. The physical needs of the user are the determining factors for the design of the envelope, and most comfort-related parameters can be directly controlled and manipulated through appropriate conception and design. The focus of this new course was to allow students to gain a deeper understanding of building envelopes, with a special emphasis on the functional, performance, and assembly criteria that are considered when developing design concepts for a building's skin.

Most importantly, the course covered an aspect that is not always addressed in a technical curriculum: architectural detailing. In the past, poorly detailed cladding systems have been responsible for a large number of building envelope failures, and have caused the public to question the architect's role at times. In developing this course, it was therefore considered necessary to reaffirm the profession's expertise by properly addressing the topic of detailing.

With all this in mind, it was crucial to find the most effective way to convey the required material to the students. The goal was to devise a format that would not only allow the dissemination of sometimes technical and theoretical facts, but at the same time give students the opportunity to directly apply their recently obtained knowledge. A project-based learning approach was chosen while keeping in mind that students would invest more effort and care into an ongoing design project than into a series of disconnected exercises. Embedding the application of technology into a design environment allowed students to immediately test newly acquired ideas and explore innovative concepts using their own designs. Theories and methods were investigated through solving integrated technical design problems and not in an abstract setting.

FORMAT

The format chosen for the course was a three hour seminar which met once a week over the period of a 16-week semester. Enrollment was open for up to 15 architecture graduate and undergraduate students in advanced standing. Set up like an intensive weekly workshop, this arrangement allowed enough time for presentations, exchange of knowledge, and discussion. The course required intensive reading, active class participation, a case study analysis and documentation of a building of the student's choice, as well as an ongoing semester design project. An extensive reader containing the weekly readings was compiled by the instructor and made available for purchase to the students.

Class sessions commenced with a lecture by the instructor of approximately one hour in length. The main purpose of this talk was to convey new information which directly related to the week's particular topic and expanded upon the assigned reading. Following the lecture, a discussion on the current issue allowed students to contribute and voice their opinion. Student presentations of building case studies or reviews of the current exercise concluded each meeting.

WEEKLY SEMINAR TOPICS

Each weekly workshop session focused on one particular topic which was addressed and discussed in depth. Ranging from generic and fundamental information regarding the building envelope to highly specific and technical knowledge, the topics were related and built upon each other. Readings were tailored to suit the current theme. A sensible topic sequence was carefully chosen which allowed sessions to build upon each other and increase in complexity as the semester progressed. The following topics were covered in the weekly meetings:

- Introduction and Design Fundamentals
- History of the Building Envelope
- Environment and Energy
- The Intelligent Skin
- Materials and Properties 1
- Materials and Properties 2
- Glass Facades
- The Double Skin
- Solar Skins
- Assembly and Detailing
- Integration of Systems
- Bionic Skins
- Smart Materials and New Developments

CASE STUDY ANALYSIS + DOCUMENTATION

Closely coordinated with the weekly seminar topics, the case study analysis and documentation was conceived as a "warm up" exercise which would allow students to practice and prepare for their own design projects. Teams of two students were asked to thoroughly analyze and document a current building that demonstrated specific envelope assemblies and technologies relevant to the investigations in the class. The analysis criteria of the case study coincided with the aspects they would then later have to investigate in their own design projects and included: climate and energy concept, envelope and structure, materiality and aesthetic, and detailing and assembly.

The students chose the following projects and presented the findings of their case study analysis to the class:

- Willis Faber & Dumas Office building in Ipswich by Foster and Partners
- SUVA Insurance Company in Basel by Herzog & DeMeuron
- Phoenix Central Library by Will Bruder/DWL Architects
- Allianz Arena in Munich by Herzog & DeMeuron
- Kunsthaus Bregenz by Peter Zumthor
- Selfridges Department Store in Birmingham by Future Systems
- Mont-Cenis Academy in Herne by Jourda Architects
- Debis Potsdamer Platz in Berlin by Renzo Piano Building Workshop

The advantages and disadvantages of each of these built examples were discussed in detail. The knowledge base established through this extensive analysis and documentation then served as a useful reference for the semester design project.

DESIGN PROJECT

The semester design project formed the core of the students' coursework. It allowed them to investigate and synthesize the concepts and principles from readings and class discussions and test their feasibility and practical application in a design problem. Just like the material communicated in the weekly lectures, the semester project's individual design exercises were strongly related and built upon each other. Rather than having students work on a series of abstract and unrelated exercises, creative design problems challenged them to test concepts and translate ideas into feasible design solutions. Two students teamed up to work together on a project. On the one hand, this arrangement allowed them to collaborate with other designers like in a professional setting, and on the other hand, it improved the final outcome since a more intensive exchange of design ideas was possible.

Since the objective of the course was to specifically focus on the envelope, students were not asked to design a completely new building. Rather, the structural framework of an existing local building was chosen: The construction of a 10-story headquarters for a notable microprocessor manufacturer had been brought to a halt by the dot-com bust. The incomplete concrete-framed structure was scheduled to be torn down to make room for a new building, but served as an ideal basis for this design investigation (Fig. 1). The goal of the design project was to develop a new envelope concept for this structure. While the roof of a building is considered part of a building's envelope, emphasis for this exercise was put on the vertical facades and their performance.

Fig. 1. Structural framework for the design project

The design project itself was made up of six strongly coordinated exercises. Each individual assignment investigated specific aspects related to designing a building and in particular its envelope. Depending on the complexity of the particular problem, the students had two to three weeks to develop a possible solution. Each exercise was presented by the design teams in the weekly sessions and reviewed by the whole class. The relationships of the building skin to other important subsystems such as the load-bearing structure, the mechanical systems, and the interior spatial framework were important characteristics and were considered throughout the entire design process. The six assignments were broken down as follows and will be discussed in more detail below:

- Exercise 1: Envelope + Structure
- Exercise 2: Environment + Climate
- Exercise 3: Materiality + Proportion
- Exercise 4: Energy + Shading
- Exercise 5: Detailing + Assembly
- Exercise 6: Final Presentation

Students were asked to develop a consistent layout and format for their drawings which would be used for the presentation of their work throughout the entire semester. In the end, it would allow them to compile the individual exercises into one comprehensive, integrated technical design project, cumulating in a worthwhile addition to their design portfolio.

Exercise 1: Envelope + Structure

In the first assignment of the semester project, students were asked to examine the link between envelope and structure, as well as their dimensional coordination. The goal of this exercise was to have students realize that the relationship of the building envelope to the load-bearing structure has a significant impact on its detailing, performance, as well as appearance. They explored the positioning of non load-bearing facades and how the resulting geometric relationships would determine the extent of envelope penetrations, the detailing of connections, and the structure's role as an expressive architectural element. Their decision on the final positioning would also considerably influence the building skin's performance with regards to deformations, thermal bridges, soundproofing, and weather-proofing.

From personal experience, it was apparent that students often struggle with the dimensional coordination of structure and envelope, and therefore they were also asked to explore building grids as part of this assignment. They studied primary structural grids for load-bearing elements and secondary planning grids for non load-bearing components such as cladding systems. An investigation of coinciding and offset grids revealed how their arrangement would influence the efficiency and regularity of cladding modules and as a result, the overall design and appearance of a building.

At the end of the exercise, students critically evaluated the envelope-structure relationships and building grid alternatives they had developed and were asked to choose one of them as a basis to continue their design investigations in the future assignments.

Exercise 2: Environment + Climate

Having established the basic relationship between structure and building envelope, one of the most important aspects for students to consider was the regional climate within which they would be working and designing. Climates can be defined by temperature, humidity, wind, and sun, and come with opportunities as well as restrictions. Depending on location, different climate conditions can be advantageous or unfavorable. A building has to operate within these given parameters, and maximize the use of opportunities while minimizing the negative effects of the specific climate zone. The main goal was for students to consider the environmental and climatic conditions of their building site and how they might influence the buildup of the envelope.

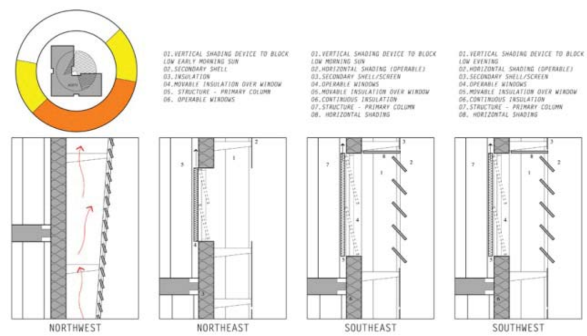

Fig. 2. Schematic envelope assemblies

After locating their building in the applicable climate zone, students established a set of design priorities. They then proceeded to develop possible solutions for each design priority and set up a series of diagrams taking into account orientation, ventilation, shading, day lighting, insulation, and weatherproofing. The resulting guidelines or design principles allowed students to start making basic assumptions regarding the composition of the building's enclosure. Paying close attention to microclimate, site-specific issues, and surface orientation, they were able to develop generic wall sections for each facade of their design project (Fig. 2). Without taking materiality and detailing into consideration at this point, students established basic interrelationships of the individual layers that make up the building envelope and determined the role each layer plays within the assembly. The conceived set of schematic envelope assemblies served as a useful guideline and reference throughout the students' design process, and assisted them in generating strong design ideas that were in keeping with the regional climate requirements.

Exercise 3: Materiality + Proportion

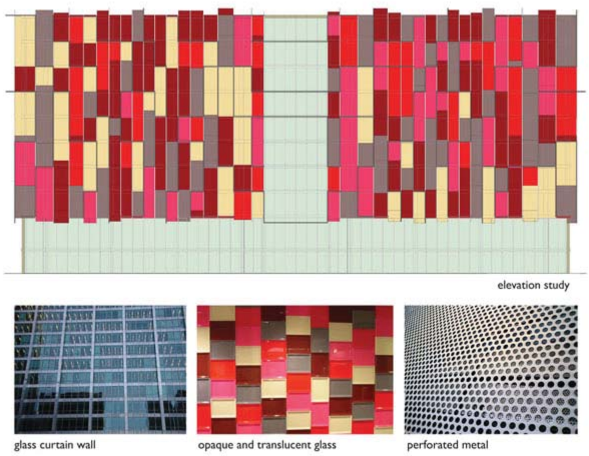

Fig. 3. Material and proportion study

After developing important fundamental design criteria in the preceding assignments, students started exploring their own architectural language in Exercise 3 by addressing proportion and materiality of their facades. Since it is often necessary and common to investigate several design alternatives in professional practice, the students were asked to generate a number of options. This systematic approach allowed for easy comparison and objective evaluation of different schemes and helped them to arrive at the best possible design solution.

Choosing one of their building grids from Exercise 1 as their base drawing, the students started investigating proportional relationships of their building elevations and developed three different schemes. They explored horizontal and vertical formats, story-height facade elements and smaller divisions, as well as modular systems and random sizes; they also looked at the placement of transparent, translucent, and opaque facade elements such as windows, shading devices, and ventilation openings. Furthermore, they were asked to develop three different material palettes which would be appropriate for the building in its context and particular climate.

To conclude the exercise, students combined each proportional study with each material palette which resulted in a design matrix comprised of nine different facade options (Fig. 3). Using color, transparency, and opacity in their elevation drawings to indicate material selections, the students were able to establish a set of facade explorations which served as a useful chart when comparing their different design schemes.

Exercise 4: Energy + Shading

Keeping the ideas and findings from the previous assignments in mind, the students were asked in this exercise to develop concepts for the integration of renewable energy sources into their building envelope. Simultaneously, they were also expected to investigate different types of shading devices for their facade systems.

Since buildings today consume large amounts of energy and are responsible for significant greenhouse gas emissions, the need for the built environment to contribute to energy generation is evident. The envelope with its exposure to sun, wind, and light is especially well suited for this purpose. The students considered systems that create energy for heating, cooling, and electricity, while keeping in mind the physical implications and constraints they impose on the assembly of the facade. The challenge was to successfully integrate these aspects into the building envelope, but at the same time allow flexibility to keep up with the latest technological developments. The students were also asked to examine the possibility of combining shading and energy generation into one system, or whether it was more useful to keep them independent from each other. Within this context, they investigated and developed sun shading and light guiding systems to minimize solar heat gain and control interior day lighting levels.

The students developed innovative concepts for effective energy generation and sunlight manipulation by experimenting with opaque, transparent, and translucent systems; internal and external positioning; as well as fixed and movable devices. All the while, they also ensured that their final solutions coordinated well with the ideas and concepts they had generated in the previous exercises so far.

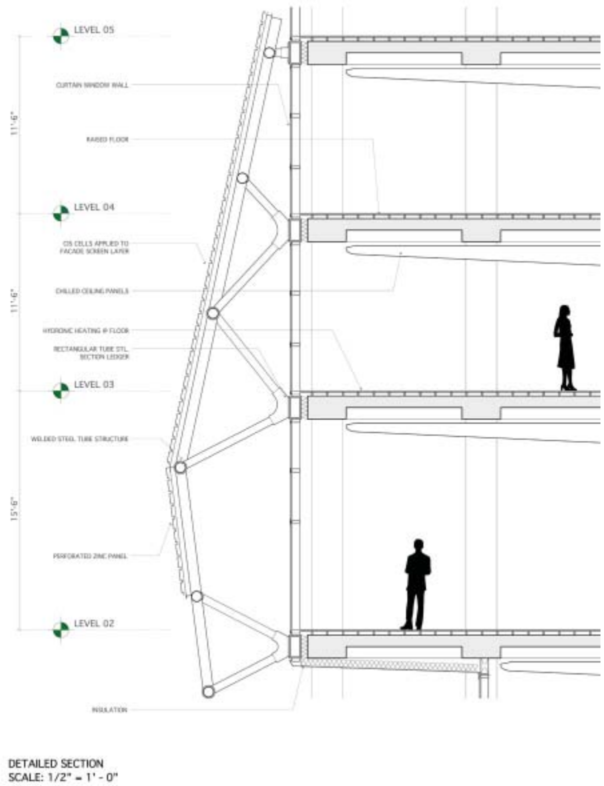

Fig. 4. Detailed section drawing

Exercise 5: Detailing + Assembly

Now that the students had established a basis for developing the building and its envelope in detail, the next task was to synthesize the collected design information. They were asked to summarize the ideas they had explored in the first four exercises and to combine them into one large-scale section drawing that illustrated their building envelope concept (Fig. 4).

It was required that their drawing contain systems that addressed the functions of weatherproofing, day lighting, ventilation, insulation, shading, structure, and energy generation. The students carefully labeled their drawings and identified all the individual elements and materials used. Critical dimensions were included to convey the scale and physical relationships between components. Close attention was paid to the proper use of line weights since this is crucial for the generation of a legible drawing.

The detailed buildup for the building's skin was developed, thicknesses and precise relationships of the individual layers were determined, suitable materials for the specific design climate were selected, and the integration with other systems was coordinated. Since all these decisions had a significant impact on the architectural expression and external appearance of the building, the students had to ensure they translated their findings into a feasible solution that was in keeping with their initial design intent.

Fig. 5. 3D computer models of envelope assemblies

Exercise 6: Final Presentation

After reviewing, correcting and reworking the section drawing from the previous assignment, the main objective of the final exercise was to bring together all the ideas and concepts developed by the students throughout the semester and to combine them into one consistent presentation of their building envelope design.

As part of the final review requirements, the students provided a partial floor plan, a detailed section, as well as diagrams illustrating ventilation, day lighting, shading, and energy generation concepts. A 3D computer model or large scale physical model of a typical floor had to show a partial facade elevation and also needed to demonstrate material selection, relationships of individual components, and issues of assembly (Fig. 5). Inspirational imagery was used to explain and illustrate concepts and design ideas.

The review format allowed the students to synthesize and process the knowledge collected throughout the semester and to present their final designs just like in a studio course. The final presentation documented an entire semester's work in the form of a comprehensive, integrated technical design project and would serve as a significant contribution to their design portfolio.

COURSE EVALUATION + STUDENTS' COMMENTS

Even though the course was open to both graduate and undergraduate students, there was a high percentage of graduate students enrolled in the course. Many of them were post-professional students in their last semester and working on their thesis project. The students' advanced standing allowed for a highly productive environment and critical discourse throughout the semester.

Since the class was taught by the instructor for the first time, the students' feedback has been extremely important for a successful evaluation of the course's chosen format, learning impact, and lasting value. The university's course-instructor survey results served as a useful tool in assessing teaching accomplishments. The students gave the course 4.5 points out of 5, which is considered to be an excellent overall rating for a technical subject. Even though 40% of students noted that the workload was high, 14 out of 15 found the class educationally valuable. The students' written comments were very positive and will be extremely helpful in future preparations for this course. Below are some excerpts of their observations and suggestions:

"This course covered material at a depth not normally encountered at [the School of Architecture]."

"This class has it all: fun and continuous design application of a wide spectrum of covered material that seems a great practice and theory-based continuation of environmental controls and construction courses …"

"I have taken other sustainable technology classes (…) and I would say that this class (…) has superseded all my expectations – considerably adding to my knowledge base."

"This course covers very important material not otherwise addressed in the context of design …"

"As a post-professional student, I only wish that this course had been available to me at my undergraduate studies. I feel that the class should continue to be taught (…) and be available at this size/format. It is successful as a current model."

"This course has been an excellent conclusion to my academic career (…) I think that a course like this in tandem with integration of sustainable design becomes almost mandatory for those wanting to research the more specific aspects of contemporary building practice."

CONCLUSION

This course begins to address many pressing issues with regard to teaching technology which are present in architecture schools across the country today. The project-based learning approach allowed students to immediately apply their newly acquired technical knowledge, test theories and concepts, and translate ideas into feasible design solutions. They were able to learn that solving technical problems as part of the design process could be enjoyable, and that attention to architectural detailing could contribute to significantly improve the quality of their buildings. The students experienced that the presence of physical and technical constraints in the design process did not have to be a creativity-limiting factor, but could in fact constitute a liberating yet challenging aspect. By obtaining knowledge and learning new techniques in a meaningful context and not in an abstract setting, they were able to improve and refine their personal design process.

Based on the students' positive feedback, the course achieved its objective in making technical knowledge more attractive, accessible, and relevant to the students. The goal in the next few years will be to encourage an even better coordination and integration of this course with the existing environmental controls and construction courses in the curriculum. Emphasis will be on furthering the integration of systems throughout the design process, advancing architectural detailing skills, and establishing performance-based criteria for the design of building skins.

As part of a comprehensive architectural education, this new approach has the potential to greatly advance the teaching of building envelope design. More sustainable design processes, enhanced building performance, reduced energy consumption, and ultimately an improvement of the built environment in the years ahead could be the result.

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