The use of models in teaching *General Building Engineering* to architects

Teresa Kusionowicz

Cracow University of Technology
Kraków, Poland

ABSTRACT: Nearly forty years' experience in teaching *General Building Engineering* to students of the Faculty of Architecture allows the author to take a detailed look into the changes occurring in the process. One of the more significant issues in building solutions is the considerable advancement in construction technology that took place during this period. Structural elements of the building are no longer single-material solutions, more and more often they form a multilayer structure. Assembling a structural system of the building from such complex components requires adequate spatial imagination, which is a growing problem for newer generations of future architects. Despite the options that arise from computer visualisation, one has failed to achieve better results in terms of quality of students' spatial imagination. Creating traditional, even rough preliminary, models is still most efficient in this respect. The aim of the article is to present the benefits of creating models in the process of teaching General Building Engineering to future architects.

Keywords: Building structure, spatial structures, visualisation, teaching

INTRODUCTION

In a broader sense, architecture is an art of organising a fragment of space in which the consciously composed form has structural grounds and artistic features. Architecture is primarily connected with meeting human needs [1]. Building engineering is a subdivision of technology (field of engineering knowledge) dealing with the principles of building design, construction and maintenance. If some practical problems appear in the process of erecting a building, then, solving them falls within the scope of building engineering. However, if there are aesthetic issues beside the practical ones, then, solving them falls within the scope of architecture. These two fields are essentially inseparable and, therefore, it is necessary to study architecture and building engineering simultaneously. Every building structure should meet three basic conditions: first, it should fully match its purpose; second, it should be consistent with good construction practices; and finally, it should satisfy aesthetic feelings. The fulfilment of the first two conditions falls within the scope of building engineering, whereas the fulfilment of all three of them is the purpose of architecture.

Building engineering is, therefore, a science which constitutes the fundamental basis of the professional skills of an engineer architect. The knowledge from the field of building engineering is the science, which includes theoretical and practical knowledge necessary for both the design and construction of buildings. Along with the development of building construction techniques, this knowledge is becoming more and more extensive and complex. Unfortunately, assimilation of this knowledge is also becoming increasingly challenging for the students of the Faculty of Architecture, especially in terms of such spatial and three-dimensional structures as the elements of vertical access system or steep roofs. Due to the energy efficiency requirements, modern building solutions consist in multi-layered elements of the building's material structure. The interpenetration of partition structures constructed in such a way is an extremely complex issue, sometimes difficult for future architect engineers to imagine and understand.

AN OVERVIEW OF BUILDING ENGINEERING TEACHING METHODS

In the past, an aspiring builder learnt the art of building from a master craftsman during apprenticeship. That has been by far the best form of learning about their future profession by young people. However, the first books which had the aim of passing on the acquired building knowledge to future builders already started to appear in ancient times. They were more descriptive with regard to construction issues, while drawings referred mainly to formal solutions. Designers and building contractors were simply called builders for a very long time. Slowly, in the period between the 16th and 18th

Centuries, that title was replaced with the term architect. The term is derived from the Greek, where the word *architektón* meant a master builder [2]. Along with the progress of knowledge and development of new building construction technologies, the knowledge from the field of building engineering began to be primarily transferred through books. In the 20th Century, that method became the ultimate method of teaching building engineering, while teaching future engineer architects their profession in a practical manner was reduced to the minimal form, which the so-called building practices should be regarded as. As a result of this change, the role of spatial imagination, which a prospective architect should undoubtedly possess, has increased. Building manuals tend to present building structures in the form of one-dimensional reference drawings, either as projections or cross-section drawings, which is, after all, the form they should be, and are usually shown, in design drawings. However, in many cases, this form has proved insufficient to illustrate the structure composed of multiple components, even in the case of flat elements, such as wall or ceiling structures.

The element which is particularly difficult to understand is the place where vertical partitions - walls - and horizontal partitions - ceilings - connect in order to limit and protect people's living space from all sides. An important and previously sufficient help in understanding how to shape and execute more complex elements of the building structure was provided by drawings of these elements in an axonometric form [3]. Yet, spatial imagination will always remain the most essential component enabling to understand the principles of constructing a building. Many years of experience gained during nearly forty-year period of conducting building engineering classes at the Faculty of Architecture allow the author to claim that there has been a visible deterioration in the characteristic, which is so essential in the profession of an architect among the students of architecture during this period. In the current economic and commercial situation, the access to professional internship for the entrants to the art of building - future architects - is extremely difficult, not so much in the case of design, but the actual building construction. Thus, teaching and studying building engineering at universities is becoming more and more difficult.

New energy-efficient technologies, more complex in their internal multilayer structure, further complicate the issues related to the interpenetration of structural, even flat, elements of the building. One can observe an even greater difficulty in understanding the interdependencies and progress in the case of three-dimensional construction components, including such vertical access system elements as ramps and stairs, as well as steep roof structures. Therefore, construction of preliminary models has been introduced to the process of teaching building engineering for the last ten years. Their purpose is to help students understand and represent three-dimensional elements of the building structure in the form of simple spatial projections.

PRELIMINARY MODELS OF STAIRS

a) b)

Figure 1: The pictures show the preliminary models of: a) a spiral staircase; and b) bifurcated winder stairs made by first-year students at the Faculty of Architecture, CUT, in the design classes of General Building Engineering.

The elements of vertical access systems are the first spatial, three-dimensional structural components of a building encountered by future architects at the Faculty of Architecture of Cracow University of Technology in the process of acquiring knowledge from the field of building engineering. Stairs and staircases deserve special attention in this type of construction. The spatial configuration of these elements results from the exceptionally important function performed by such structures. They are building structures designed to link different levels of a building located both inside and outside. In the case of a multi-storey building layout, this building element is a multi-flight staircase, i.e. a room specially allocated for stairs inside the building or added to it. These solutions enable users to move between the different functional levels of the building. To satisfy human physical needs, spatial solutions for stairs must meet specific requirements in terms of the physical dimensions of the human body, in other words, these must be ergonomic solutions.

The multi-level room within which a staircase is located imposes an additional requirement, which designers must meet - ensuring safety of use. A particularly important element in the design and implementation of stairs is the entrance to a higher level through a hole of appropriate size adapted to the shape of stairs, which is specially formed in the ceiling structure. Flights of stairs can be variously shaped on the floor plan - they can be rectangular, winder, curved or spiral. Also, flights can be arranged in many ways within staircases. In the case of a staircase composed of many rectangular flights, there might be straight, quarter-turn, dogleg and, finally, bifurcated stairs. Shaping this building element itself provides an extremely complex number of options that become significantly expanded by the variety of locations and connections of the structure to the whole building structure. Understanding all these spatial conditions is extremely difficult, especially for people with poorly developed spatial imagination. Unfortunately, there are more and more people like this even among the students of architecture. Constructing a preliminary model facilities these people's understanding of the structure's shape to a great extent. Such a preliminary model serves to show the spatial arrangement of individual structural elements constituting the stairs' structure. It indicates the additional components that need to be used within the building structure in order to form a hole in it, which would allow for the transition between levels and which will be the basis for the construction of stairs.

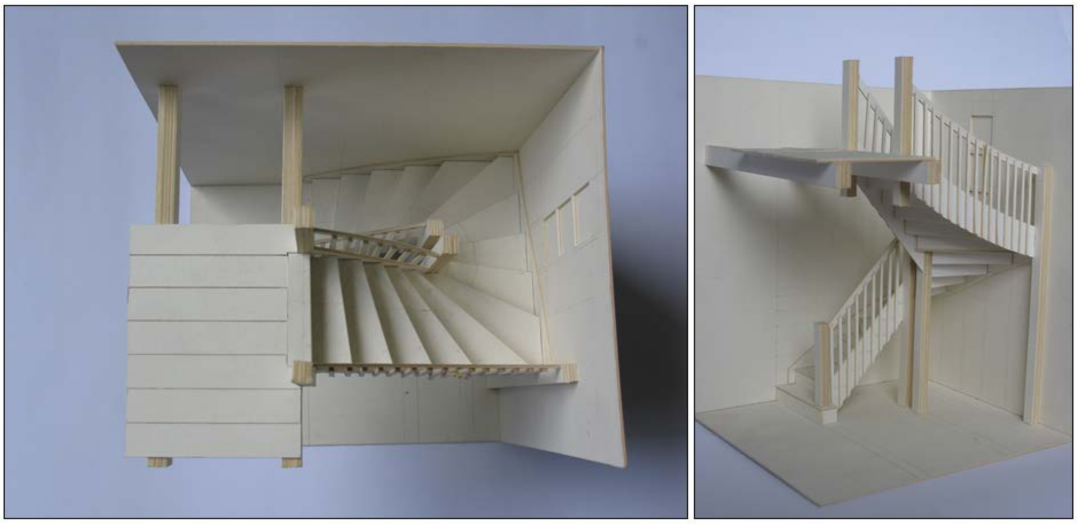


Figure 2: The picture shows the preliminary model of winder stairs made by a first-year student at the Faculty of Architecture, CUT, in the design classes of General Building Engineering.

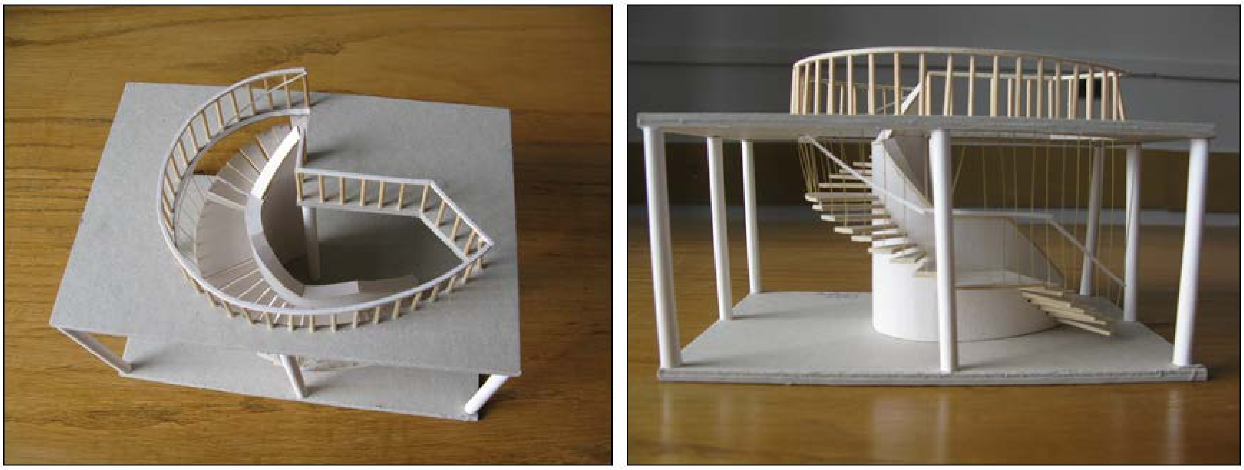
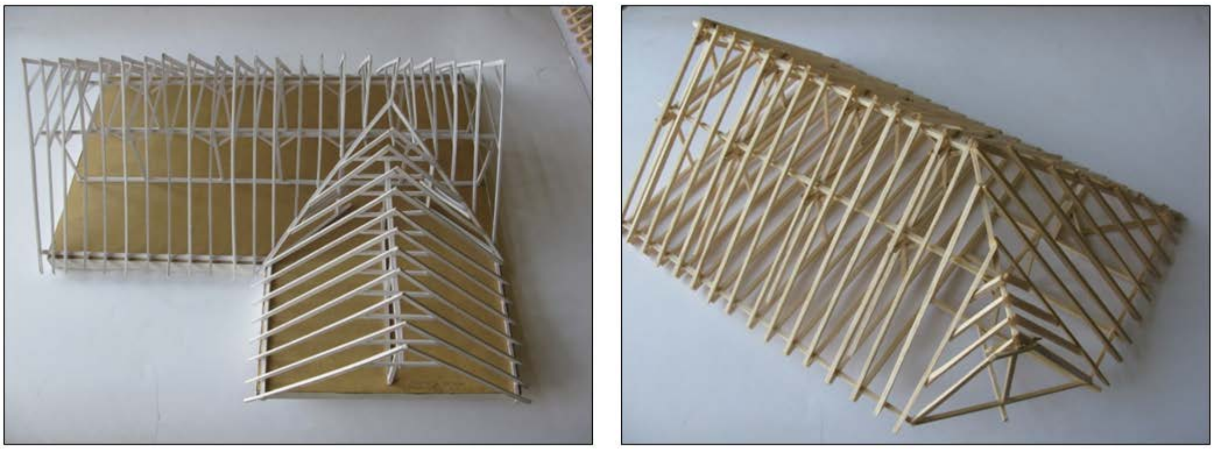


Figure 3: The picture shows the preliminary model of winder stairs made by a first-year student at the Faculty of Architecture, CUT, in the design classes of General Building Engineering.

PRELIMINARY MODELS OF STEEP ROOF STRUCTURES

Another building element that the first-year students of architecture become familiarised with in the process of studying building engineering is a steep roof structure. The traditional, but still used, structures of this building element are mostly made of wood. They come in a variety of shapes as their role is to protect the building from weather influences and to keep rainwater off the building. The more extended and fragmented the plan of the roofed building is, the more complex the formation will be. Drainage requires the formation of an adequately sloped roof.



a) b)

Figure 4: The pictures show preliminary models of roof supporting structures: a) collar beam roof; and b) purlin roof structure made by first-year students at the Faculty of Architecture, CUT, in the design classes of General Building Engineering.

To obtain the building's coping shaped in such a way, it is necessary to construct an appropriately formed structure supporting its decking and watertight covering. The structure is found in the case of wooden roofs constructed from timber beams, which are suitable in terms of durability. The structure made of such beams creates a three-dimensional spatial element of the building structure. Supporting a steep roof with differently shaped structural elements varied in terms of construction types complicates the application of this type of solution even further. Structures placed on the fireproof load-bearing ceilings are simpler in form than roof structures based only on the building's load-bearing walls or the wooden ceiling. Providing such a structure with an adequate rigidity requires the arrangement of beams in a very complex way. Vertical poles and horizontal supporting elements or sloping elements, mainly those forming the plane of slopes, but also the ones stiffening or suspending load-bearing elements are used in these solutions.

All of these beams create extremely complex spatial arrangements, whose representation in the design drawing in the form of projections and cross-sections requires even more spatial imagination than in the case of the construction of stairs. Making even the simplest preliminary model enables one to see and understand the relationships that exist in the space between particular beam elements in these solutions. These are not simple relations and, admittedly, not structural ones, but they do constitute their prototype in a sense. Having such a model in front of the eyes, it is easier to imagine which elements of the structure are presented in a cross-section or a view on the projection plane adopted in the design, and which ones should not be included in the drawing at all. The students have confirmed that the construction of such a model has clarified how to resolve the supporting roof structure properly, and enabled them to perform their course design.

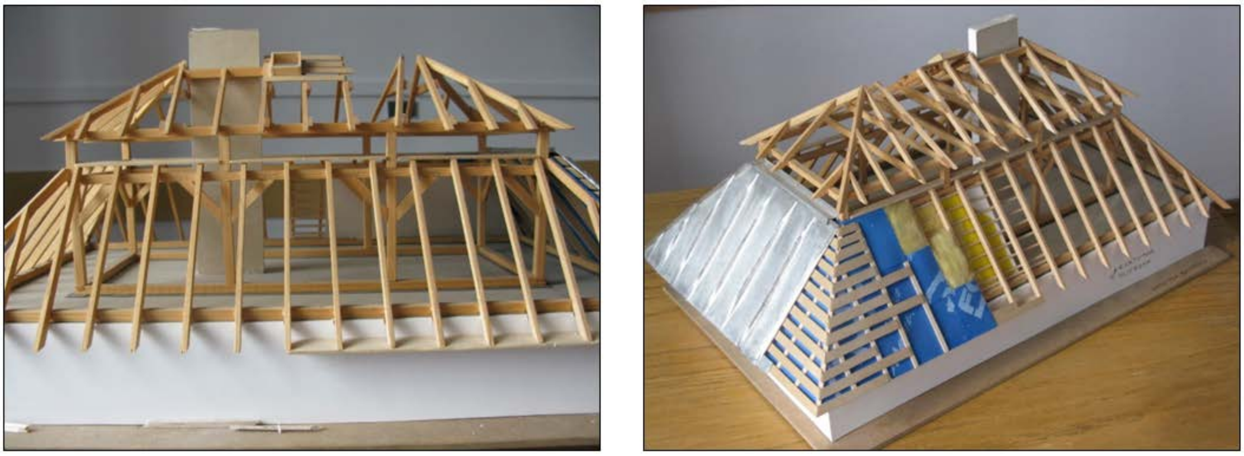


Figure 5: The pictures show preliminary models of Cracow mansard roof made by first-year students at the Faculty of Architecture, CUT, in the design classes of General Building Engineering.

MODEL OF A SINGLE-FAMILY HOUSE FRAME STRUCTURE

Making models for the designs of stairs and roofs has proved so helpful to understand and prepare design drawings that some of the second-year students have made an effort to prepare other models on their own, with no such requirement imposed on them. They found it especially useful at the time when they encountered difficulties in developing a structure system for the pre-designed concept of the development and arrangement of a single-family house. The difficulties consisted of distinctly different layout arrangement of load-bearing walls on each floor of the designed house. The problem became even more complex in the situation when the body of the building based on the specific design module was cut or overhung in many places. The preparation of a structural and architectural design for such a building was so difficult to imagine, in terms of structural and construction solutions rather than the functional and formal ones that the spatial visualisation of its solution was necessary. The model of the arrangement of the frame structure's load-bearing elements, which was the only one possible to use in this particular situation, allowed one to retain all the functional and formal solutions proposed in the concept of the designed single-family house.

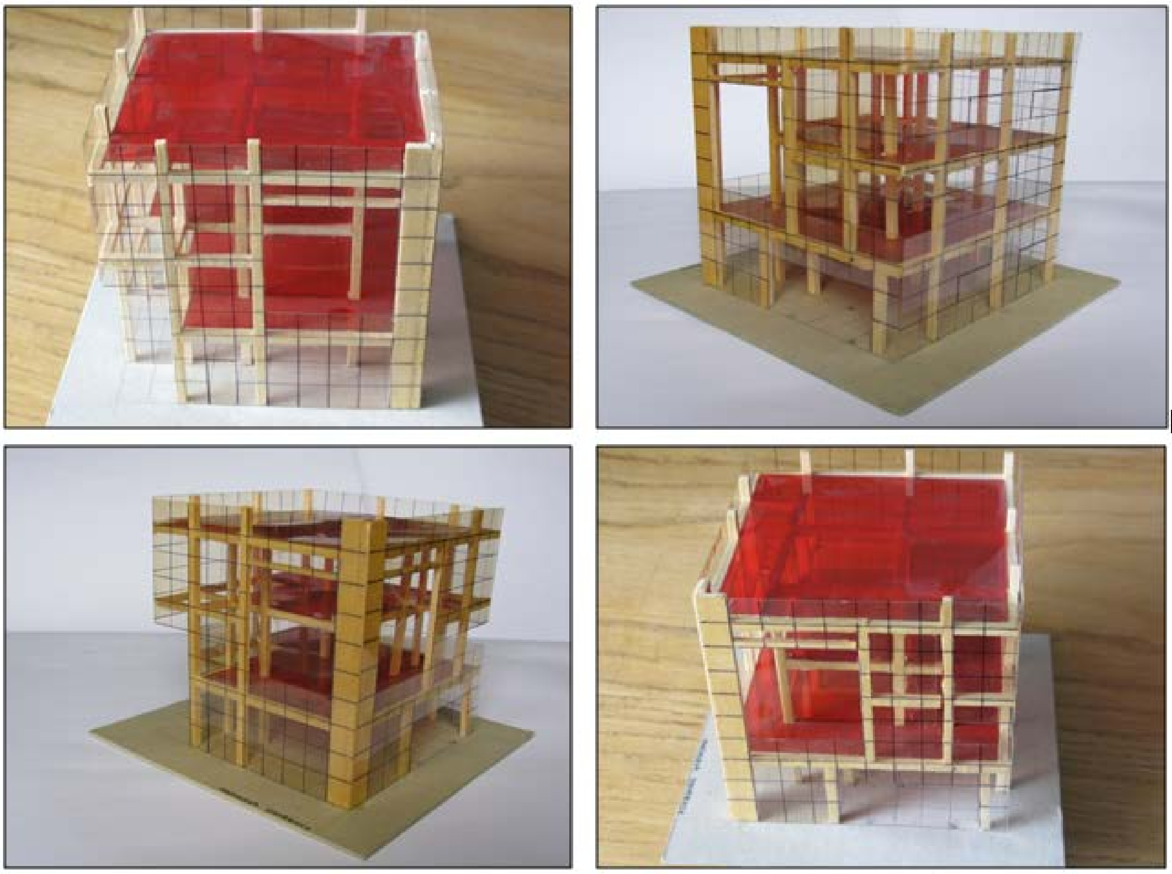


Figure 6: The pictures show the preliminary model of a single-family house frame structure made by a second-year student at the Faculty of Architecture, CUT, in the design classes of General Building Engineering.

CONCLUSIONS

Making preliminary models for individual structural parts of the whole building structure is a valuable complement to the process of teaching General Building Engineering to architects. In the absence of opportunities to participate in the construction of buildings directly, it remains the only way to illustrate the physical principles of solving and constructing various elements, which form the material structure of the building. Computer visualisation cannot replace this action. Visualisation is performed on the basis of prepared design study. By contrast, the purpose of a preliminary model is to help prepare a correct design and accurate solution of a structure system for the chosen element of the building structure.

The preliminary model is constructed during the design process, whereas computer visualisation usually occurs at the end of the design process as a presentation of formal solutions. Computer visualisation does not correct the appropriateness of the applied construction and building solutions as opposed to the model-based design. Model-based design is closer to the physical reality and reflects principles of statics occurring in this reality better. Without taking into account the physical principles of statics, the proper construction of both the entire building and its individual components is impossible.

REFERENCES

1. Wojda, A., *O Projektowaniu w Architekturze*. Monograph 26, Cracow University of Technology, Kraków (1984) (in Polish).
2. Krajewski, K., *Mała Encyklopedia Architektury i Wnętrz*. Wrocław, Zakład Narodowy imienia Ossolińskich-Wydawnictwo. 153-443 (1974) (in Polish).
3. Mączeński, Z., *Poradnik Budowlany dla Architektów*. Państwowe Wydawnictwo Techniczne, Warsaw (1953) (in Polish).

Teresa Kusionowicz (MArch, PhD, DSc) is the Deputy Director of the Institute of Building Design in the Faculty of Architecture at Cracow University of Technology (CUT) and Head of the Department of Building Technology in the same Institute. She began her studies at the Faculty of Architecture (CUT) in 1972. Due to excellent results in examinations and social work, she was awarded the *Primus Inter Pares Nicolas Copernicus Golden Badge* for the best CUT student in 1977. In 1979, she was awarded the degree of Master of Science, Engineer in Architecture. After completion of her studies in 1978, she started in the A4 Institute's Department of General Building Engineering and Building Materials at the Faculty of Architecture, CUT. In 1980, she began working as a research and teaching assistant, and since 1983 as a senior research and teaching assistant. In 1986, she graduated from the four-term Postgraduate Studies of Monument Conservation in Architecture and Urban Planning. In 1992, she defended a doctoral dissertation (with distinction) and received the title of Doctor of Technical Sciences. For her achievements in the field of science (doctorate), she received the individual 2nd degree Award of the Rector of Cracow University of Technology. In 1992, she began working as an assistant professor in the Department of General Building Engineering and Building Materials. She has been Head of the A4 Institute's Department of Building Technology since 2009. On 26th May 2010, on the basis of her academic achievements and habilitation thesis entitled *Projektowanie Budynków Mieszkalnych a Zdrowie Człowieka. Wybrane Zagadnienia (Designing Residential Buildings and Human Health. Selected Issues)*, the Council of the Faculty of Architecture, Cracow University of Technology conferred a postdoctoral degree in technical sciences in the field of architecture and urban planning with specialisation in architecture. As an employee of CUT, she is engaged in teaching and conducting research, and design work in the field of general building engineering devoted to contemporary and historical construction techniques. In 2009, she was awarded a Badge of Honour of Cracow University of Technology for her teaching, research and organisational activities. Since 1994, she has been participating in the work of the Intercollegiate Team for the Teaching of Building Techniques on Polytechnic Departments of Architecture. In 1999, she was elected a member of the Division of Building Engineering in the Commission of Architecture and Urban Planning at the Polish Academy of Science.