Steep roof design: a combination of history and geometry as part of an interdisciplinary education for architects

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ABSTRACT: Described in this article are several of the author's contributions to steep roof design, which is part of the Construction course taken by architecture students. The course is run by the Institute of Building Construction in the Faculty of Architecture at Cracow University of Technology (CUT), Kraków, Poland. This project demands new skills from students. At an early stage of their education, students are expected to make an important transformation in thinking, from flat 2D drawings to 3D spatial architectural objects. Steep roof design is considered difficult by students, because of the numerous relations between elements and the sophisticated shapes used in construction. At the same time, steep roofs are a part of Poland's historical legacy from which the traditional technology takes, in Polish, its name. The sequence of tasks for students from easy to sophisticated is seen by the author as parallel to the *historical evolution* of roofs. Conclusions resulting from the article are informed by the author's teaching experience. Examples of teaching materials and students' works produced as part of this programme are presented in this article.

INTRODUCTION

Steep roofs are an established part of the Polish national heritage. The *Zakopane style* was even named as a *Polish style* of architecture at the beginning of Poland's independence after World War 1. However, the implementation of steep roofs have undergone a gradual evolution since then.

Figure 1: Zakopane is considered to be the city symbolic for Polish steep roofs. But, the aerial view shows the more complex aspects, especially the change of relationship between flat and steep roofs in different time periods. See the text for discussion. Photo by R. Marcinkowski, 2014.

Figure 1 has been chosen to illustrate the characteristic trends in steep roofing during the past century. The roofs visible on the photo are a result of the following processes.

The Historical Period

The natural evolution of folk technologies is visible in the construction of roofs. The characteristic aspect of such an evolution is that improvements appear gradually and almost never have a specific originator. Thus, the folk architecture can be described as a reaction to climate conditions by using poor available materials and techniques.

The process of repetition and gradual improvement established a set of building techniques and forms characteristic of the region. The steep roof forms expanded to other regions, eventually creating a national legacy. Luckily for traditional roofing nowadays, there still exists a *fashion* of timbered log houses with steep roofs, both as seasonal and single-family buildings. The word *fashion* implies that private investors may often ignore potential defects resulting from the use of old-fashioned technologies. The problems of traditional carpentry in meeting modern requirements were earlier described by the author [1][2].

Competition between Steep and Flat Roofs

The next important period for traditional steep roofs in Poland was the rivalry or competition between flat and steep roofs. The second half of the 20th Century saw the so-called *block age* in architecture. Folk-building traditions were officially approved by the communist authorities, but were in fact perceived as inconvenient and not enough controlled. Flat roofs and later the concrete prefab architecture were presented as functional, dense and modern. This was the subject of discussions and argument between the authorities and society, and also within the group of designing architects. But, generally the *invasion of the blocks* gave the results mostly visible in the central (upper and lower) part of Figure 1.

Present Day

At present, more and more precise requirements concerning regional forms of buildings are stated in building laws. Precise rules for the implementation of steep roofs are related to other regional requirements. However, the dichotomy mentioned above still exists, in altered form. The lobbying for non-regional or over-regional modernity flow from the world of business, and authorities try to defend the regional character of the architecture by means of official restrictions.

STEEP ROOF DESIGN IN INTERDISCIPLINARY TEACHING

The values of traditional roofs and their role in Polish architecture demand incorporation into academic didactics. The most familiar subject to the author is *construction*, dealing with the engineering aspects of design. The author's experience includes several years of conducting student groups, and about four years of conducting construction lectures in the Faculty of Architecture, CUT. The steep roof design occupies the second half of the second semester, which means approximately eight weeks of work with groups of 15 students. The relatively short time at an early stage of the students' education, leads to a compressed programme.

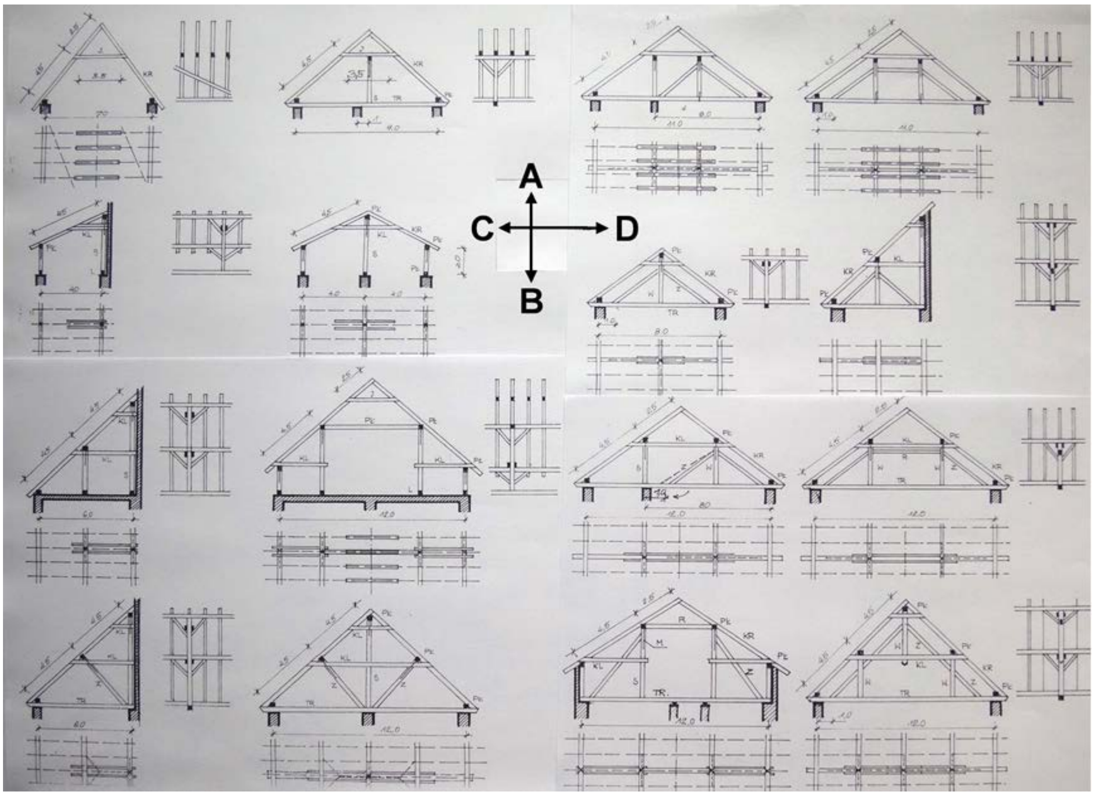

Figure 2: Example of groupings of roofs enabling quick comparisons.

Figure 2 shows basic types of traditional roofs. The A - B and C - D arrows indicate basic divisions of roof types, viz. A: Collar-type roofs; B: Purlin-type roofs; C: Structures supported by load-bearing elements of the building; D: Self-bearing structures. This teaching material is a result of team work. Compilation and description are by R. Marcinkowski, while drawings are by Katarzyna Klakla, a PhD student in the Institute of Construction Design, CUT.

Important relations between technology and education are interdisciplinary, and concern several teaching subjects that need to be better integrated. To create at least a possibility of integration, the author provided input to the design of several courses:

1. History of Polish Architecture course - by choosing types of roofs related to historical sources and possibly still existing in traditional construction.
2. Dwelling Architecture Design course - by pointing to specific relations between roof construction and the functional needs of dwellings located in attics.
3. Building Structures course - by including in the programme basic relations between the length, loading and cross measurements of beams and also the solution to structural problems with the rationally smallest use of materials for each type of construction.
4. Building Materials course - to include both the psychological and physical qualities of wood, and ecological aspects of construction including the sustainable sources of materials.
5. Descriptive Geometry course - by the demand for precise measurement and situating the constructional elements in three-dimensional space. The steep roof design has a level of geometrical difficulty requiring spatial imagination.

In spite of its interdisciplinary nature, there should be uniform standards for the teaching materials, such as:

1. The grouping of materials should enable quick comparisons and easy understanding by students (see as an example Figure 2).
2. The presentation of knowledge on a small number of drawings (see as an example Figure 3).
3. The use of special non-repetitive graphics concerning roof constructions. These are practically non-existent in the official Building Law [3] or norms [4].

SUBJECT CHARACTERISTICS

Steep roof design is a part of the Construction course run by the Institute of Building Construction in the Faculty of Architecture, CUT. The second semester is split between two projects, staircases and steep roofs, requiring from students new skills. Especially, the steep roof design is considered by students as difficult, because the students need to visualise in 3D. This skill is only partially assessed on the entrance examination to the University.

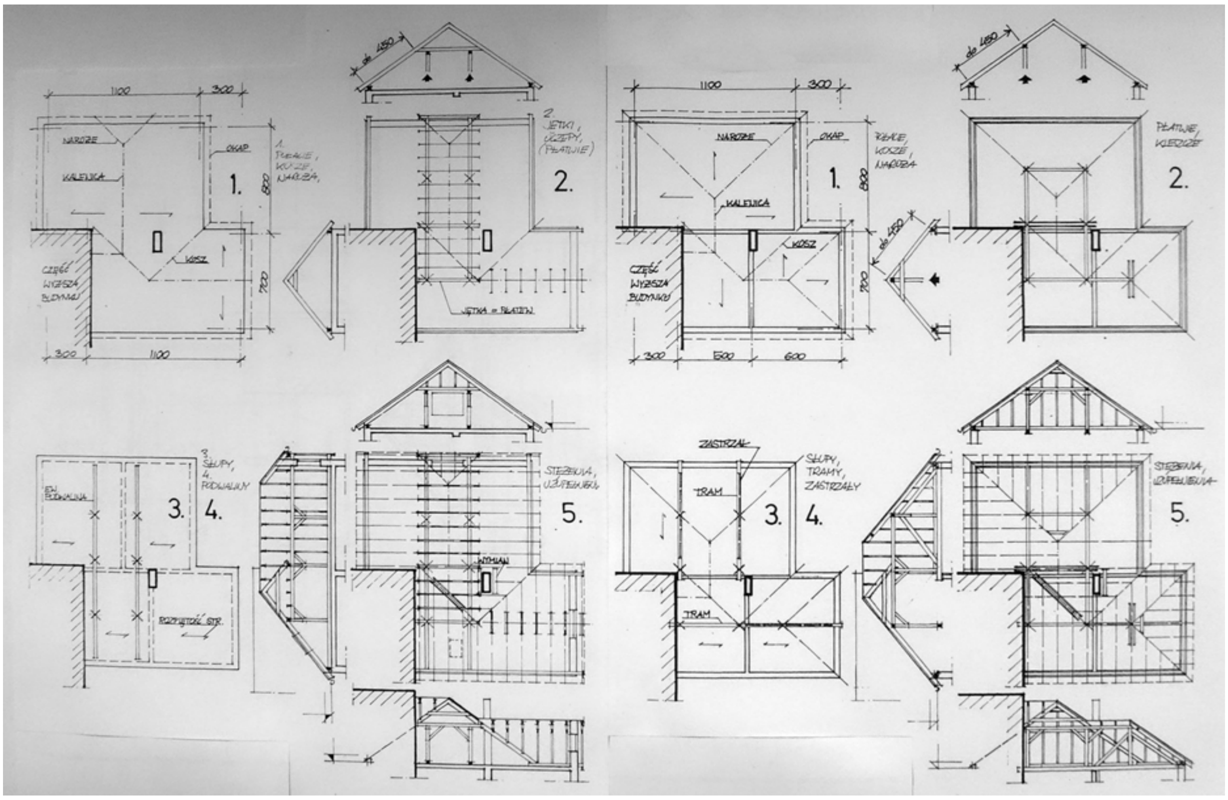

Figure 3: An example of teaching materials – the five steps of design (drawing by R. Marcinkowski).

Figure 3 is an example of teaching material showing the five steps of design. On the left in the figure is a collar-type roof on a load-bearing floor slab. On the right in the figure is a purlin-type, self-bearing roof. The design steps are:

- Step 1: the precise shape of the roof;
- Step 2: system of collar beams (left) or purlins (right);

- Step 3: standing and hanging posts;
- Step 4: sole plates (left) or tie beams (right);
- Step 5: struts, brackets, corrections for spatial rigidity.

Theoretically the training requiring this degree of visualisation is supported by the descriptive geometry course. However, the problem is that students taking many separate courses rarely make good use of the knowledge coming from one course in another course. The problem of insufficient co-ordination between teaching programmes has been raised by the author [5].

A problem is the graphic representation of the roof construction. It differs a lot from the typical, horizontal section of a building. In the standard projection rafters covering the roof totally hide other elements placed beneath, like collar beams or tie beams, making the reading of the drawing extremely difficult. That is why only horizontal elements of the roof construction are shown in the normal projection, while inclined elements (such as rafters, struts or brackets) are shown symbolically by two kinds of dash lines.

The example of teaching materials shown in Figure 3 was developed in order to minimise the number of drawings necessary to illustrate a roof structure. The shape of the roof, the upper part of the plans, is partially based on the two most popular types of roof present in small buildings, i.e. the collar-type and the purlin-type roof. These are also described in the majority of textbooks. Such a compilation based on the same plan of the building gives an opportunity for quick comparisons between basic traditional constructions.

Referring to Figure 3, the roof on the left is typical of newly built functional attics, with normal windows in vertical gable walls. The system of collar beams creates a flat ceiling. The positions of posts can be changed easily, according to functional needs, both in longitudinal and in the cross direction. The roof is structurally supported by a load-bearing floor slab. The purlin-type roof on the right was a construction typical of traditional hip roofs. In modern buildings, it gives an opportunity for cathedral ceilings and a higher functional space. The supporting self-bearing system of struts and tie beams, omnipresent until the first half of the 20th Century, is nowadays used only for decorative purposes. However, architects still often encounter these in attic adaptations of older buildings.

The shape of both roofs shows modifications of the basic types, i.e. on the lower right of both plans the intersection is with a roof of similar type, but of smaller dimensions, whereas on the lower left the shape and construction is in relation to the adjacent higher part of the building. For simplicity some details were eliminated, e.g. longitudinal curtain walls of attics and the structural divisions between buildings.

The most important aspect of this teaching material is the presentation of the design process as a sequence of logical steps, leading to a sophisticated result, but with each step being relatively easy, when considered separately. The process of solving the roof design task has been divided into five steps:

1. Defining the precise shape and the angle of all surfaces of the roof. This may depend on many regional, functional, and generally non-constructional factors, not listed fully in this article. Dividing the surface of the roof into fields (slopes) and their edges: hips, valleys, ridges, eaves and rakes.
2. Provide proper support for rafters depending on their length. Analyse the possible positions of supports as a distance from a roof plate to the ridge. Preliminary position collar beams or upper purlins.
3. Provide support for collar beams and upper purlins from step 2. Analyse the number and the possible positions of posts.
4. Situate posts on different types of floor slabs. In the case of self-bearing roofs, situate posts on tie beams. Ensure the proper direction of tie beams. Take account of standing and hanging posts.
5. Maintain the spatial rigidity. In self-bearing roofs, support the hanging posts by struts. Optimally position the struts, brackets and collar ties. Correct and determine the final positions of rafters and collar beams.

STEEP ROOF DESIGN IN THE ACADEMIC CURRICULUM

Probably the most effective change to the educational process would be to shift the class of Construction to later semesters, so that it would better connect with other classes of architectural design. Such a change would enable students to modify their conceptual projects; thereby, improving the formal continuity of architecture, as well as increasing the value of technology. The design of a steep roof then would be incorporated as part of a larger project. The standard project task for students (its graphical part is shown in Figure 4) is based on small-scale structures defining the shape and type of construction. The total size of the roof and the difficulty level is similar, but all tasks include irregularities and never just follow the examples in textbooks.

Graphical schemes are shown in Figure 4 and provide brief illustrations. The project task for students includes the following:

1. Roof construction plan at a 1:50 scale (examples in Figure 3, step 5). Requirements include, among others, the special engineering graphic.

2. Cross and longitudinal sections, 1:50 (examples in Figure 5, the left part), with precise vertical positioning of every element of construction.
3. The model of the roof - this is now mostly handmade, but in previous years it was an axonometric view, or computer 3D model, as shown in Figure 5, on the right. The choice between a computer or handmade model should be left to the student.
4. Details of the traditional carpentry joint, in two directions at 1:20, with the spatial intersection of elements of the roof construction presented with precise measurements.
5. The detail of the section at 1:20 with the functional use of the roof space for apartments. The detail includes elements of the drainage system and materials used for finished walls and floors.
6. The list of wooden structural elements, including lengths and cross section measurements. One of the demands is to specify precise lengths of diagonally positioned beams.

The requirements for projects evolve over time. From the author's point of view, what is important now is not a precise analysis of the details of required drawings, but rather to make some remarks of a more general nature.

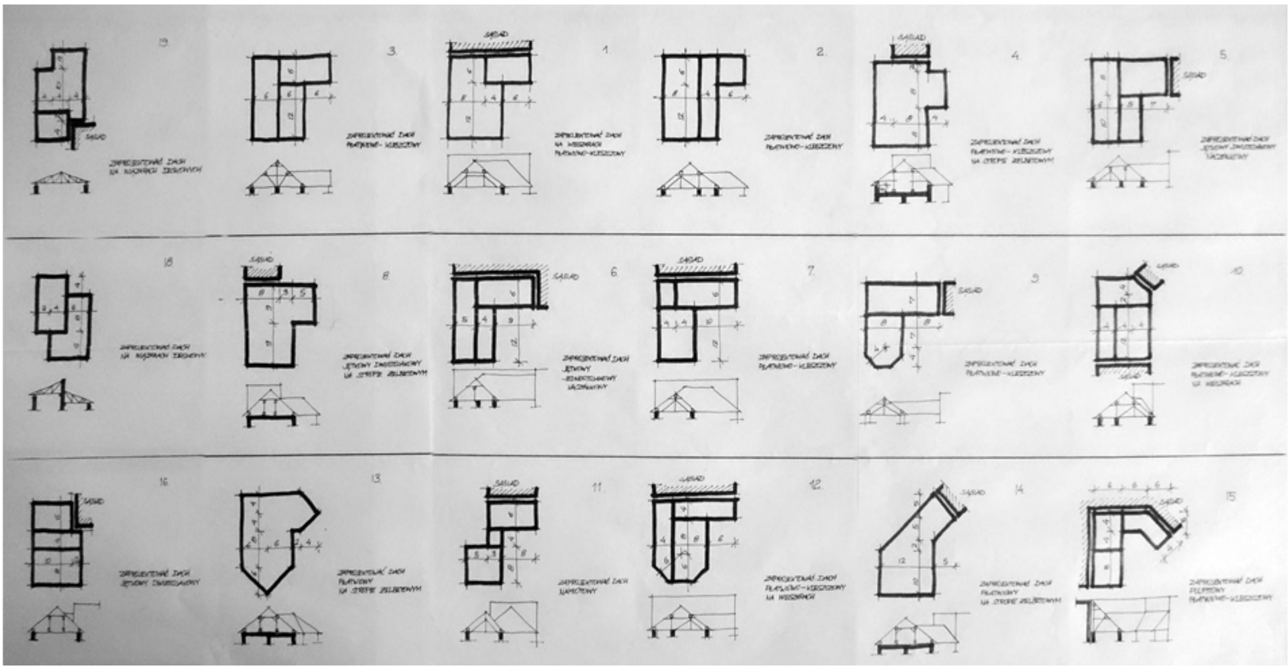

Figure 4: The set of project tasks has multiple variations of shapes and available supports for roof construction, but in fact represents a few traditional solutions for the roof structure. Drawing by R. Marcinkowski.

The steep roof design is produced by students in their first year. At this point in their education, students have limited computer skills and are required to make drawings and models by hand. But, giving students the freedom to decide how to proceed can give a better result than by having a set requirement. An example of a student-created computer 3D model is shown in Figure 5, bottom right. This is of higher quality than could be achieved in a model made by hand.

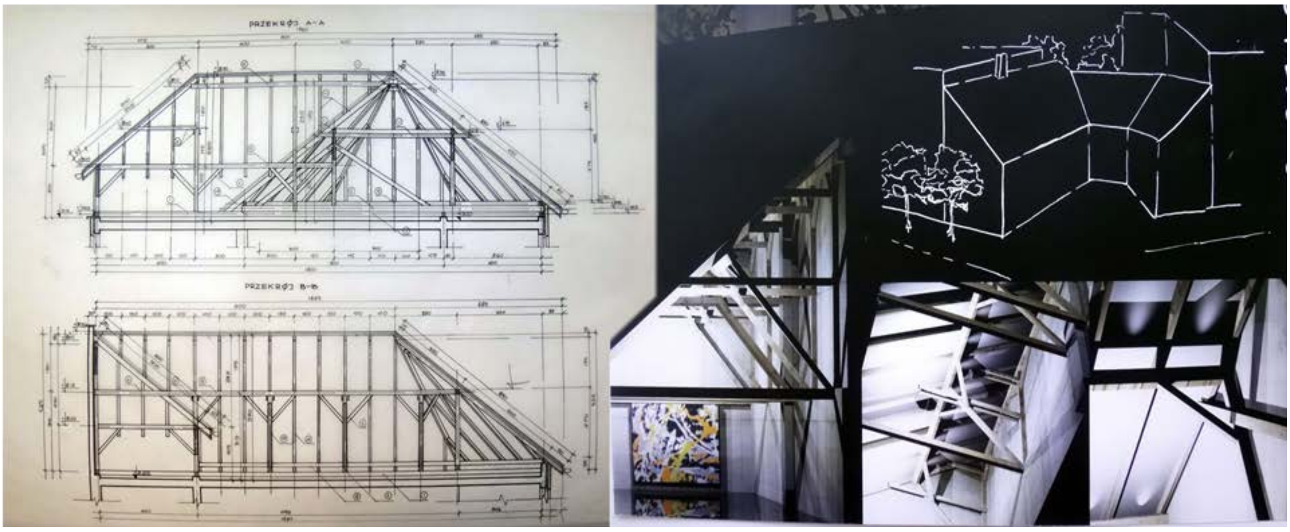

Figure 5: Examples of students' drawings skills using different disciplines, including a freehand drawing and a computer 3D model. Drawings by students Tomasz Gniadek and Piotr Gierek, Construction class.

The technology of traditional carpentry should not be forced as an obligatory demand, but rather as an attractive option as a symbol of cultural continuity of the architecture. The problem is that during the first semesters such humanistic issues are absent from most students' minds.

Many students memorise the graphical form of drawings as a sequence of triangles, squares, etc. This enables students to reproduce mechanically a simple drawing during an examination without understanding the relationships between the elements drawn. For this reason, the project tasks should not be *oversimplified*, since a properly made drawing is difficult to distinguish from a mechanically copied one.

Note of Explanation

An important note should be made regarding the use of this work as a reference. The teaching materials shown or mentioned in this article are the basis of the roofing curriculum in the class of Construction (Faculty of Architecture, CUT). They were developed, evolved and perfected by the author during a long period of professional work until circa 2013, but were never published. Thus, in spite of their educational importance, they cannot be used as a standard reference.

The obstacles for publishing the materials in the form of a book or textbook were usually either financial or editorial. A relatively new problem is the system of university staff assessment, which awards zero points for this kind of work.

CONCLUSIONS

A teaching programme obviously requires teamwork. The author's contribution was mostly the compilation and the *compression of knowledge* into a small amount of teaching material.

The richness and complexity of teaching programmes, including technical matter, is a positive factor in engineering education and generally seen as evidence of the quality of a university. An important threat is that the atomisation of teaching causes a student to encounter a large number of seemingly unrelated, separate subjects. A large number of classes in these separate subjects overloads students by unavoidable repetition and impoverishes final learning. But, even more dangerous is the students' impression that knowledge gained from other teaching is not relevant to the present teaching. As well, this leads to internal contradictions, i.e. unconscious and fortunately marginal questioning of teachers' knowledge.

Teaching materials developed in different institutes should be at least partially *cross referenced*. Such connections can make the educational process holistic and internally consistent.

It is not possible to introduce an effective integration by acting within one subject only. The significant result can only be achieved by multilateral and interdisciplinary teaching programmes. At the present time, the integration of subjects, into an interdisciplinary whole, are more discussed than implemented.

In the case of the education of architects, an interdisciplinary programme should include some humanistic content, e.g. philosophical or historical, going beyond the scope of engineering education.

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