Proposals for the training of specialists in Architectural Engineering

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Abstract.
The article examines the building as a product of the construction industry within the development of Civil and Architectural Engineering. Studies have shown that neither of these fields can fully cover the entire construction process. Increasing disparity between architecture and engineering is identified. A unified undergraduate university programme of Architectural Engineering is proposed. This can provide an effective synergy between architects and engineers within their shared practice. Specialisation (in the fields of architecture, building structures, engineering equipment etc.) is proposed for postgraduate studies. Such training of professionals can give way for improving the quality of the construction industry.

Keywords: Civil Engineering, Architectural Engineering, Construction Product, Study Program, Synergy

1. Introduction

For a long time, the construction of the building was carried out under the supervision of one person, whose titles were changing with different times: a builder, an architect (meaning "construction manager" in Greek), an engineer. Since the second half of the twentieth century, the functioning of a building was increasingly dependent on its engineering system. Architecture and engineering (the machinery and technology of the construction) are closely related. Therefore, a building, as a product of quality, is possible to be constructed only with the use of complex knowledge and practical achievements, with the creative collaboration (synergy) of architects and engineers of varying

specialisations. Practices are slightly diverse in different areas of the globe, but there are far more similarities than differences. A building must meet not only functional, aesthetic and reliability requirements, but also those of sustainability. Architecture and engineering were a single professional entity up until they started to split around the middle of the nineteenth century. Over time, architecture has drifted closer to be an art form, while civil engineering has branched out into more narrow specialisations (engineers of building structures, building technologists, heating and ventilation, plumbing, sewage, electrical and other engineering specialists).

A situation when the architects have occupied a privileged position has already become typical in the design stage: they alone determine the future construction concept. Engineers simply retain a passive role of architectural solution materialization. The building constructor and other engineers, who could have been active and responsible professional at the stage of configuring a building's form, became merely technical performers. In the second half of the twentieth century, due to increased price of energy resources, structures (especially buildings) were being designed as more and more energy efficient, and their architectural-planned solution was often closely related not only with the structure solution, but also with the solutions of heating, ventilation and air conditioning systems. Development of information technologies was influencing the engineering solutions of structures more and more as well. It should be stated that when construction becomes more complicated from an engineering point of view, the role of the architect decreases even in the design stage. Upon completion of the construction, during the utilisation of the building, services of an architect are sometimes needed for the repair, reconstruction or modernization works. Usually, throughout the utilisation process, the ones involved in it are mostly engineers. Finally, the process that engineers are mostly involved with is the demolition of a building. Therefore, as mentioned above, the last century, together with civil engineering, saw the emergence of architectural engineering as well. The article attempts to define the content and the boundaries of those two construction directions' developments, and to discuss the improvement opportunities of relevant specialist training.

2. Civil Engineering

The term *Engineer* in English, *Ingenieur* in French means "toinvent, to construct"; (in Latin *Ingenium* refers to "the innate ability, the talent, especially the mental ability, the invention" (around 1250)). The term *engineering* is derived from the word *engineer* (dating back to 1325, literally – "the owner of a mechanism"*)*, and was originally associated with military machinery constructors, and later (after 1500s) describes their functions [7]. In a now-forgotten meaning, the term *engine* has been associated with warfare technology (e.g., a catapult). The term *engineering* was associated with military engineering units and is now not defined as such anymore.

The situation changed when civil engineering (as an antonym of military engineering) appeared and included the construction of civil buildings. Civil engineering, as an occupation, has existed from the beginning of time and from the first attempts to build any structure [13]. In Antiquity, engineering was more of an art form than a scientific discipline because here was no known or commonly used systematised scientific engineering knowledge. Traditionally, civil engineering has been divided into the following fields: building construction mechanics, material science, constructional technology, heating, ventilation, sewage and water supply, surveying, hydrology, geotechnics and environmental engineering [1]. With the evolution of production methods, construction materials and technologies, traditional craftsmen eventually transformed into today's professionals. The technical training changed from an apprenticeship to a university degree. When trade unions emerged, professional meetings and various publications accelerated the exchange of information. Professional civil engineering, as we

know it today, appeared in the nineteenth century - it was registered as a field of study in 1792. In 1818, the Civil Engineers' Union was established in London. In 1828, this uningrained a royal charter, which formally recognized civil engineering as an independent profession. In the eighteenth century, architects performed most of all works of design, which today are carried out by civil engineers. In the nineteenth century, responsibilities and the authority of architects of designs became narrower due to an increase of professionalism and specialization of structure designers in the seventeenth century. Because of the general natural evolution of human-produced output, structures were becoming more and more complicated. The industrial revolution created the conditions for mass consumption and, consequently, aesthetics became an important factor even for middle-class people – ornamented products, once luxurious and hand-made by craftsmen, became less expensive due to industrial production. Throughout 1750–1850, industrial revolution in Western Europe had a significant impact on the construction industry development [13].

In the work environment of the nineteenth century, architects were making their careers in fields ranging from draughtsmanship or clerkship to significant architectural practices. At the same time appeared the so-called noble architects, who worked mostly for wealthy customers. They mostly found inspired architectural expressions in historical prototypes. The architect's role in the society became more and more prominent. In the nineteenth century, the abundance of technically oriented civil engineering knowledge grew, more sophisticated construction technologies appeared, and the architecture field became narrower. Reaching the professional status, the architects wanted to be accepted not as mere artisans and, eventually, they aimed to stand out from civil engineers.

The modern practice of construction shows that the main criterion of a building, as of a product, is its cost-effectiveness. Function, aesthetics and even reliability have all become second-class criteria and are addressed in the elaboration of a design concept. A building's structure is less and less reliant on its functional purpose; buildings of varying functions are often subject to a same design solution (this usually concerns monolithic or part-assembled concrete, or steel frame structural systems). Later, a building is "clothed" with glass clothes, and the planned solution is "free". At this point, there are less and less artistic elements within architectural design, and the skills of artisans are often sufficient for the building planning solutions. In a building's design, architecture as an artistic expression works only when unique buildings are being composed.

The modern definition of civil engineering is known to be the following [2]: "…the profession in which a knowledge of the mathematical and physical sciences gained by study, experience, and practice is applied with judgment to develop ways to utilize, economically, the materials and forces of nature for the progressive well-being of humanity in creating, improving and protecting the environment, in providing facilities for community living, industry and transportation, and in providing structures for the use of humanity."

3. Architectural Engineering

While the construction science had advanced substantially in the nineteenth century, knowledge and techniques within the discipline had already accumulated over a long time. Start connected with the mathematical reasoning and a design of static load-bearing structures and the structural analysis. Heating and ventilation systems, whose role is crucial within modern construction, had developed in the eighteenth century. With the development of design and construction methods, new phenomena appeared in the construction field in last few decades of the twentieth century and in the twenty-first century: technological progress, innovation in constructional organisation methods, the emergence of specialisations in parts of building design and construction execution; construction investment

planning, economic solutions and calculations based on the entire lifetime of the building, which ensures the efficiency of the building not only after its construction, but also throughout long-term use as well: emphasis of environment protection, sustainable design and construction principles; over the past 50 years, design and construction are becoming more complex and legally regulated; throughout 1800-2000, social, cultural and technological revolutionary changes have been stimulating the assessment of the feasibility and reliability of engineering systems [12].

Nowadays, design and construction of structures are facing new noticeable challenges, alongside with a variety of favourable circumstances. Mandatory technical, legal and cultural knowledge is so broad and deep that no single profession of the construction industry can cover it, and to be responsible for all the building-related knowledge and experience like the ancient architects were [4]. The construction process members are responsible for research of the right interaction of design, science and technologies. For each specific building design, a group is brought together, consisting of professionals from a variety of specialists, and later of contractors of different expertise areas.

The Architectural Engineering study program, which appeared at the end of the nineteenth century, has been preparing specialists for working in the construction industry at the junction of architecture and civil engineering. The emergence of such a program was not random; it had been driven by the construction industry evolution. It was expected for a long time of architects to have the technical knowledge and the construction engineers would be aware of parts of architectural design. In 1890, at the Illinois Institute of Technology (USA), the formal preparation of architectural engineering professionals was started, and the term *Architectural Engineering* was used for the first time [5]. The preparation of architectural engineering professionals was carried out on the experience basis of earlier civil engineering study programs, holistically preparing students for practical activities, and it was already prevalent in the 1st decade of the twentieth century in the USA.

In 1910, the Department of Architectural Engineering at the Penn State University (USA) was established and the now-world's oldest accredited architectural engineering degree program was started in 1936. In the middle of the twentieth century an increasing number of universities began to prepare a new type of professionals: architectural engineering specialists for working in the construction industry. Already in 1946, the Architectural Engineering Department was established in California Polytechnic University, in the Faculty of Engineering. The key fields of the study program were the architecture and structure of the building, and in 1950 the Architectural Engineering Department was established in the newly formed faculty. By the beginning of the 9th decade of the twentieth century, the goal of the architectural engineering study program had become to "fill the gap" between architecture and engineering. Today's social circumstances increase the demand for architects with fundamental knowledge of constructional disciplines, so that graduates can produce high-quality multifunctional buildings. This is why it is so important to promote the areas synthesis that exist in architectural engineering. However, architecture was separated from civil engineering (many architectural engineering study programs were in civil engineering faculties), most architectural engineering programs lost art subjects. However, from the minimum of programs (8 university study programs in the early 1980s) and when the concept and the definition of the *architectural engineering* changed to “engineers of building engineering systems”, the number of architecture engineering programs nowadays is growing. Our studies have found over 60 different graduate-degree programmes all over the world [6]. Many of them were launched within the last decades. In the 1990s, the architectural engineering certification emerged, initiated by the United States Council (*National Council of Examiners for Engineering and Surveying*), and, since the first group was certified in April 2003, Architectural Engineering has become recognized as an autonomous specialisation in the United

States. The US construction engineering union established the architectural engineering department. Now there are 17 universities in the US with different levels of combinations of architectural engineering degree programs. The analysis of the study programs' content shows that in different institutions the architectural engineering covers different dominant fields of study: building materials, construction technology and project management, energy saving and sustainable buildings. Particular attention is paid to the building engineering systems (structures, heating, ventilation, etc.), their improvement, design, installation and use. Study programs are taught to integrate all engineering systems into construction. However, there is also an architectural engineering program where the credits of the architectural design courses even account to 95% (*October 6 University*).

In the USA, architectural engineering graduates are known as architectural engineering professionals, while in Canada, the United Kingdom and Australia the profession is known as *Building Engineering* or *Building Services Engineering*. Within the accredited USA architectural engineering programs there is "the design, installation and maintenance of engineering systems and engineering parts of the structure design in functional, cost effective, stable, aesthetic buildings" [3, 5].

Due to the cooperation of various construction industry professionals in the construction designing process and development of innovative and sustainable construction techniques for future generations, architectural engineering is increasingly becoming a construction industry direction [9]. This direction includes all the technical construction activities, provides the attention to structure constructions and other parts of the design prepared by engineers, building materials, organization of construction works, the management of technologies and projects, takes into account provisions related to the environmental impact of the building, technical, economic, sustainability requirements. Architectural engineering promotes an integrated and holistic approach to the design, construction and operation. Today, implementing sustainable projects, heating operation, ventilation, electricity, water supply and sewage disposal specialists is very important, and their significance and creativity is compared to the influence of designers of high-rise building designs [8].

4. University Bachelor Studies of Architectural Engineering

The times when one person could design a structure and lead its materialisation have irreversibly passed. A building has become a more and more complicated product, but its quality is still largely determined by the general work of various professionals involved in the process, their synergistic activity. Therefore, their mutual understanding is very important.

In 2000, in Lithuania, Vilnius Gediminas Technical University, started a bachelor's degree programme, and since 2004 master's degree programme of Architectural Engineering. Creating these study paths, we aimed for the preparation of professionals who can produce two parts of the building design: architectural and structural. Therefore, in the study program we tried to achieve a balance between art (architecture) and engineering (mainly structural mechanic) parts. Our programme's graduates subsequent work performance shows that such architectural engineering specialists are in great demand. After analysing the global preparation practice of architectural engineering specialists [6] and our own teaching experience, we have put together a model of an architectural engineering specialist [10]. Researching architectural engineering university studies [6] in 60 universities around the world that offer studies of architectural engineering, we were able to identify only 33 universities where detailed study programme structures are public and available. The programs we have tried to compare, are grouped by its study subjects into three blocks [11]: A - general subjects of university studies that cover higher education subjects of philosophical world outlook and general erudition; B - subjects of study direction, that cover theoretical and professional subjects required in the exact study

programs (Technology); C - subjects of specialization. The comparison results are presented in the Figure.

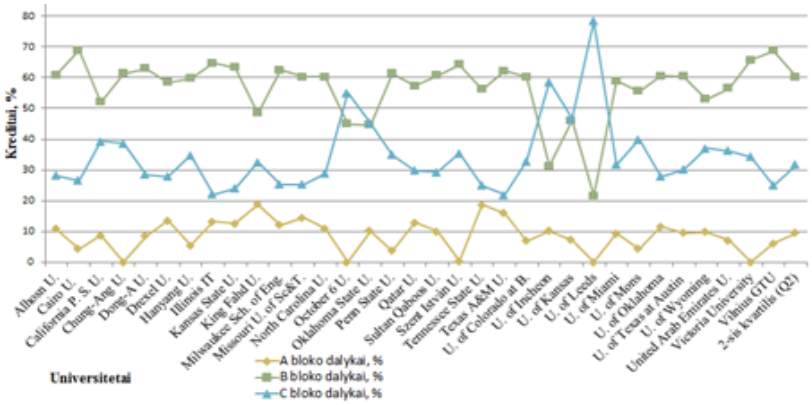

Fig. The Comparison of Credits of A, B and C Architectural Engineering Study Programs in World Universities

The graph curves show a high dispersion of programs blocks credits, which illustrates the diversity of architectural engineering programmes' (specialisations') goals.

Architectural engineering development tendencies show that it becomes all-encompassing in the construction industry. Civil engineering combines all areas in the construction industry, except for architecture. The global construction practice shows that the architecture of mass-utilisation buildings construction is not an art. Therefore, preparation of professionals of design, including the architectural part of the design, can be incorporated into architectural engineering program studies. Apparently, it is time to discuss about the need of a universal program of architectural engineering university bachelor's degree. By the program, specialists would be prepared for working in the construction industry. They would receive a wide range of knowledge and skills in construction investment process. Upon the completion of bachelor's degree studies, master's degree studies could be left for individual specialisation, covering narrow areas of the construction investment process: an architect, a structural designer, a construction technologist, a construction manager, a heating and ventilation specialist, etc. However, a united bachelor education of architectural engineering specialists would eliminate the existing gap between architecture and engineering, which is particularly relevant in the current construction development period. It would help in practical work for good mutual understanding between construction professionals as well. For these graduates it would be much easier to decide what direction of master's studies to choose after their bachelor's degree, rather than choosing specialised bachelor's degree studies, often having poor understanding of chosen specialty. In addition, the merged architectural engineering bachelor studies would help their global mobility and recognition.

The architectural engineering bachelor's degree program could be based on the ASCE proposals for Civil Engineering Bachelor study in the twenty first century [1]. The programme structure is to be divided in to three blocks as well (Foundational, Technical and Professional).In the beginning, it is possible for structure of Architectural Engineering Bachelor unified programme to take advantage of the ASCE proposals and of our analysis of architectural engineering study programs throughout world universities. The analysis performed shows average values of the block of architectural engineering study programs in 33 world universities are (Fig.): A - 10%, B - 60%, C - 30%.Since the proposed program is non-specialized, it makes sense for B and C blocks (in ASCE those programs are Technical

and Professional) to merge. In that case, up to 90% of the program credits could be devoted to theoretical and professional specialty subjects of architectural engineering, including art direction (for artistic expression, architectural composition and architectural design we suggest assigning about 20% weight within the 90%). Up to 20% can be assigned to structural mechanics, up to 30% to other engineering systems, and up to 20% to construction management and economy. An approximate set of items in blocks is given in the table.

Table. An exemplary set of courses for the unified program

Blocks	**Academic courses**
A	Social sciences Mathematics Construction physics Material science Information technologies and integrated design
B+C	**5. Art direction:** Artistic expression Architectural composition Architectural design Architectural history **6. Structural mechanics:** Statics Dynamics Reliability Building structures Layout of bearing structures Structural engineering design **7. Building engineering systems:** Sustainability Heating, ventilation, culling Water supply Wastewater Electricity Fire safety **8. Construction, technology:** Construction economics Construction work technology Management Business and public administration Work safety

Such preparation of the Architectural Engineering degree program and its realization would allow preparation of construction industry professionals with knowledge, skills and enough understanding, and would allow effective synergic integration of all the specialists involved in the output, as a product, of a building.

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