Abstract

Motivation. Modern design practice, where an architect works with engineers in a large team, lacks optimization. If collaboration between the professions of architecture (A.) and engineering (E.) were improved, it would result in more efficient structures. Collaboration can be improved by professionals who have training and/or experience in both professions. The concept of architectural engineering (AE) appeared in the late 19th c., and the profession has increasingly been developing from that time on. There were a number of designers in the building environment who had been educated in both professions and who successfully practiced on the border between A. and E. The Aim of the research is to develop a competence model (CM) for the AE professional, and scientifically substantiate the subject matter of the undergraduate AE program. The Scope of the study is the analysis of collaboration issues relating to the civil engineering (CE) and A. professions, and also of the training issues of the AE professional. Results. The authors developed an AE professional competence model.

1. Introduction

The modern practice of building construction presents great changes in the way of design and construction delivery. Structures contain a large number of specific and complex architectural and engineering – structural, technological – solutions. Structure and function are inseparable parts of the building design. Therefore the process of designing and constructing the structures requires professionals possessing knowledge and experience in both architecture and engineering. The benefit of interdisciplinary programs has been proved for example by interdisciplinary CE programs with a major in A., and dual degree programs; pros presented by a number of sciences and building construction itself.

Methodology. Cluster analysis and personal experience were utilized in the research. Comparison analysis was done evaluating the AE study programs, reference sources on the competence models’ structure and subject matter. Statistical analysis was done with A, CE and AE study program courses. Results are presented in two Tables, and conclusions.

2. Collaboration of A. and E.

The main text should include previous research on the subject, methodology and/or theoretical framework, results of the research, and discussion and interpretation of results obtained. (Alt + Ctrl + P)E. and A., considered as one until the mid-eighteenth century, separated at the time of the establishment of engineering schools. From that time on, the relationship between the professions has evolved from their complete separation in the nineteenth century to the intense collaboration of today [1]. Interaction between the professions can be characterized by three forms: Separate activity, Interpenetration of both fields, and Close collaboration.

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In general, an architect acts like an orchestra conductor and composer in the overall process of building development. In times [3] of urgency and war, engineering becomes dominant, while in times of peace, plenty, luxury, and affluence architecture comes to the fore. Architects’ knowledge of E. is not enough for structural calculations and they therefore need the expertise of engineers. Structural courses every year in college do not make an architect proficient enough to design the structure of even a small building. If architects were to work without engineers then erroneous and unsound results could follow. On the other hand, considerable input into the modern building as regards both finances and technology is made by the engineer. As buildings become more complex, the technical part of the design has devolved more and more upon the multi-discipline engineers [2]. Even if architecture designed by engineers were “utilitarian and/or ugly” people would still live in durable, safe and healthy buildings.

During the last 200 years, construction professionals, differing only in title and performing the same services, eventually began to perform different services in the same project [3]. The services of engineers and architects participating in projects ranged from ‘minimal architectural advice whatsoever’, through to ‘architect as artist’ with the engineer as helpmate or servant [4]. Both professions have a number of things in common, and have a number of common courses in their study programs. In some designs, the structure of the building is the main aesthetic accent, often termed structural art.

There are architects who have good capacities in structural engineering and engineers who have a good knowledge of architecture. There have been or are professionals that graduated from one, both, or integrated programs (Dieste, Nervi, Candela, Isler, Fuller, Le Ricolais, Otto among others (the authors have identified more than 40 prominent professionals in this category)), who acted or are still acting as both architect and engineer, ignoring professional demarcations and blurring the professional borders. In the collaboration and search for a successful design, the disciplines actually merge into one another.

Both professionals are essential in modern construction projects. Functional needs of clients, regulatory impacts, technological advances, the use of new materials, innovations in methods and techniques, computerization of design and construction, etc., all foster a more intense dialogue and collaboration, and bring the two professions closer together. They need each other in order to develop something that neither could produce alone. The necessity of intense collaboration is proved by: a) the development of the fields, of their labels and practice; b) the training, practice issues, and current trends of A, E, and AE; c) differences in the training and practice of A and SE [5].

The division between the A. and E. that took place in the 19th c. has proved to be wrong for the design and construction process. Lack of intense collaboration hinders the development of advanced structural and technological construction projects.

3. Architectural engineering

AE is a profession that focuses on close interaction between A. and E. in the building development process. If the intense collaboration between the professions is lacking and tasks are not solved in an integrated way, there is a danger that a number of tools will not be used. The design of a structure is a solution of architectural tasks, the building’s structural system, selection and calculations of the structural model, its engineering systems, technical and economical efficiency. The essence of architectural and engineering design is the search for an optimal structural solution based on architectural function (and aesthetics). The training of AE professionals helps to diminish the increasing gap between A and E and guarantees better quality construction projects.

Today there are more than 60 AE university programs of various degree combinations around the world. The undergraduate AE program at VGTU was established in 2000 and aims to provide graduates with: an integrated knowledge of A and CE (SE) developed by building environment sciences; knowledge of technical progress, and construction investment process development; theoretical and practical knowledge of CE professional practice; personal, social and special skills in order to become engineering professionals, efficient practitioners for design and construction companies, and also governmental institutions, with the ability to improve in a dynamic environment; the ability to carry out and apply research.

The training of AE professionals in Lithuania is based on National Regulations (lith. Reglamentas) [6]. Courses in the Reglamentas are divided into three course blocks. Block A contains General University courses, block B contains Technological Science Branch courses, and block C contains Specialization courses.

The authors’ perception of AE is based on a comparative analysis of undergraduate AE program subject matter [7], and analysis of AE training and practice issues.

The analysis presents a comparison of 33 AE undergraduate programs considering a number of aspects. Block C courses in the analysis were divided into A. and E. courses. Results of the analysis show that the VGTU AE program is among the programs that have the greatest balance of A and E courses’ relative credit values in block C. There are only 6 world AE programs that have a bias of up to 5% into either side [8-13], see Table 1.
Table 1. Comparison analysis of the undergraduate AE programs. (Drexel 2013; Hanyang 2013; North 2013; Oklahoma 2013; Penn 2013; VGTU 2013).

| AE undergraduate university program | Country   | Credits for block C Architectural courses, % | Credits for block C Engineering courses, % |
|------------------------------------|-----------|---------------------------------------------|--------------------------------------------|
| North Carolina U. USA              | USA       | 45.95                                       | 54.05                                      |
| Vilnius GTU Lt                     | Lt        | 47.14                                       | 52.86                                      |
| Hanyang U. Kor                     | Kor       | 47.37                                       | 52.63                                      |
| Penn State U. USA                  | USA       | 50                                           | 50                                         |
| Drexel U. USA                      | USA       | 52.34                                       | 47.66                                      |
| Oklahoma State U. USA              | USA       | 54.93                                       | 45.07                                      |

4. Competence Model

AE program development and curriculum design at VGTU in 2000 was based on the subject matter analysis of undergraduate A and CE (SE) programs in existence at that time at VGTU. In their further research the authors aim to update the VGTU undergraduate AE program. In order to develop scientifically substantiated subject matter for the study program, a Competence Model (CM) for the AE professional, presenting the essential knowledge and skills for the architect and structural engineer, had to be developed. In order to develop the CM, an analysis was made of a number of reference books on: CM structure and subject matter of various science branches; studies and regulations on the essential competences of, and services provided by, the architect and structural engineer; differences in the training and practice of A and SE [5].

The CM for the AE professional (Table 2) proposed by the authors presents 5 competences, and includes: Professional subcompetences of the AE professional; Common subcompetences inherent to members of all building professions; Basic and General (contrary to Professional) subcompetences depicting knowledge and skills common to all individuals. All competences, except the Professional Activity competence, present both General and Common/ Professional subcompetences. The fact that the grouping of knowledge and skills in the competences is provisional should be kept in mind, because a number of skills and areas of knowledge can belong to one or another competence.

In the process of developing the VGTU undergraduate AE program subject matter, authors collected courses essential for the training of the particular skills/knowledge presented in the CM of the AE professional. All the proposed courses are divided into 13 course groups. Labels of the course groups needed for the training of the particular competences are presented in Column 4 of Table 2. These courses were proposed based on the analysis of: world undergraduate AE programs curricula; curricula of the top 11 A. and 11 CE undergraduate programs of the five continents (e.g. [14] because of [15-16] because of [17], [18] because of [19], [20] because of [21]). The proposed VGTU undergraduate AE program complies with the European Regulations on the technological program curriculum design. Presented briefly, competences include the following knowledge and skills.

4.1. Personal competence

Basic: personal and professional motivation; physical, mental and moral health; efficient completion of assignments. Self development: realization of human potential; evaluation of personal or joint activities; responsibility, autonomy, perseverance, and integrity. Analytic skills: working consistently at an abstract level; problem simulation, alternatives assessment; working under tight deadlines with minimal supervision; developing, implementing an action plan; reflective, cognitive, forecasting, design methods and techniques. Continuous Professional Development (CPD): Planning, commitment to and participation in CPD; fulfill CPD requirements in countries where they are specified; attend presentations in professional institutions from specialists in professional issues, and presentations made by manufacturers about their products. Following are essential course blocks for the training of the competence: Free Electives/Physical training; Humanities/ Social Sciences; Mathematics/ Natural sciences; Building engineering systems: Structural Engineering: Theory and Design; Professional practice courses; Arch, Engineering graphics/ Multimedia/ CAD, BIM/ Composition.

4.2. Social - Legal competence

Social: social interactions; evolution and trends of society, nature; anthropological knowledge; methods, organization of interdisciplinary activities; effective teamwork climate/morale; consideration of the social, cultural and environmental effects of activities.
Legal: Human rights; work in compliance with laws, regulations; industry, government and public contracts on project-related matters; developing project directives, time lines, resource studies, and strategies to meet relevant building/construction regulations and permits; investigation of regulations. Following are essential course blocks for the training of the competence: Building construction courses; Humanities/ Social Sciences; Language/ Communication courses; Professional practice courses.

Table 2. CM for the AE Professional. Comment: The italicized labels in the column „Course group label” present all 13 course groups.

| Competence                                      | Sub-sub-competence | Sub-competence | Course group label                                      |
|-------------------------------------------------|--------------------|----------------|--------------------------------------------------------|
| 1. Personal competence                          | Basic              |                | Free Electives/Physical training                        |
|                                                 | Self development   |                | Humanities/ Social Sciences                             |
|                                                 | Analytic skills    |                | Mathematics/ Natural sciences                           |
| Continuous professional development             | General            |                | Building engineering systems: Structural Engineering: Theory and Design |
|                                                 | Professional: Arch & SE |          | Arch, Engineering graphics/ Multimedia/ CAD, BIM/ Composition |
| 2. Social-Legal competence                      | Social             |                | Building construction courses                          |
|                                                 | Teamwork           |                | Humanities / Social Sciences                            |
|                                                 | Legal              |                | Language / Communication courses                        |
|                                                 | Professional: Arch & SE |          | Professional practice courses                          |
| 3. Communication-Information competence         | Communication      |                | Arch., Engineering graphics / Multimedia CAD, BIM/ Composition |
|                                                 | Professional       |                | Humanities / Social Sciences                            |
|                                                 | Information        |                | Language / Communication courses                        |
|                                                 | Professional: Arch & SE | Documentation | Mathematics / Natural sciences                          |
|                                                 | Professional: Arch & SE | Visual presentation, CAD | Professional practice courses                          |
| 4. Professional activity competence             | Professional practice |                | Arch., Engineering graphics/ Multimedia CAD, BIM/ Composition |
|                                                 | Technical Knowledge | Arch & SE      | Building construction courses                          |
|                                                 | Project Development, Planning, Analysis, and Design | Arch & SE | Building engineering physics |
|                                                 |                     | Arch.          | Building engineering systems: Mechanical / Electricity/ HVAC/ Water |
|                                                 |                     | SE             | Building engineering systems: Structural Engineering: Theory and Design |
|                                                 | Construction materials and techniques | Arch & SE | Geodesy / Surveying |
|                                                 | Inspection         | Arch & SE      | History, Theory of Civil Engineering, Architecture, Arts |
|                                                 | Management         | General        | Humanities / Social Sciences                            |
|                                                 |                     | Team management | Mathematics / Natural sciences                          |
|                                                 |                     | Professional: Arch & SE | Professional practice courses                          |
|                                                 | Customer and Personal Service | Common | Mathematics/ Natural sciences                          |
|                                                 | Research           |                | Professional practice courses                          |
Communication – Information competence

Communication: Knowledge of native, and at least one foreign language; business writing; provision of information to all stakeholders of the joint activity in oral/written form; making presentations in project groups; professional language; persuasively articulating services, offerings, technologies, and their business value to customers.

Information: Documentation tools, computer hardware and software; technical writing, reporting, contract documents; technical project documentation; developing new programs for special purposes; imagination; analyzing and depicting functional ideas, conceptual diagrams in drawings and reports; design techniques, tools, and principles of documents, instructions, technical plans, layouts and scale model production; computer aided design, BIM; video animation; generating computer simulations of structures. Following are essential course blocks for the training of the competence: Arch, Engineering graphics/ Multimedia/ CAD, BIM/ Composition; Humanities/ Social Sciences; Language/ Communication courses; Mathematics/ Natural sciences; Professional practice courses.

Professional activity competence

Professional practice: Profession path, nature, values, history, contemporary trends; methods of sustainable professional activities; professional ethics; design climates/philosophies; determining a project’s complexity, particular requirements; expertise/ focus in a particular professional area, for further practice/research. Technical knowledge: Mathematics, mechanics, applied and engineering sciences; principles and equipment of engineering design, and production of various goods and services.

Analysis, Development, Planning, and Project Design: Design buildings and structures, create general layouts; site analysis, geotechnical issues; technical and economic analysis; assess feasibility; provisional structures design; building performance optimization: building forensics, energy auditing, advanced computational modeling; specifications, fabrication, construction, assembling, modification, and maintenance of structures. A.: architectural design, programming/planning and development; determine the client’s needs; evaluate, translate building requirements and design solutions proposed by consulting design professionals. SE.: Design structural components and systems; develop and interpret shop fabrication or connection design; construction engineering (erection) drawings and documents; organize, review, perform, evaluate, and ensure accuracy and completeness in all structural design calculations (assisted by manual and computer methods); ability to design these with different materials; develop structural design standards for projects; structural material specifications and recommendations.

Construction materials and techniques: Knowledge of methods and materials-manufacturing processes, their properties, laboratory/field testing, and costs- involved in the construction of structures; substructure to superstructure construction techniques and equipment. Inspection: Inspection and report of structural condition, common defects and remedial works; overseeing and review of structural design and construction progress. Management: Business practices, marketing, production methods, coordination, modeling, and resource allocation; team building (also during the activity) and supervision; motivating, developing, planning and coordinating the activities of people; time management; facility/ practice/ project/ labor/ construction financial management, contract administration; review, analyze and evaluate bids, submitted tenders, cost estimates, bills of materials from multiple subcontractors; planning, organization, and team coordination.

Customer and Personal Service: Assessing customers’ needs, proposing solutions, and evaluating customer satisfaction. Following are essential course blocks for the training of the competence: Arch, Engineering graphics/ Multimedia/ CAD, BIM/ Composition; Architectural Design: Building, Urban, Landscape, Interior; Building construction courses; Building engineering physics; Building engineering systems: Mechanical/ Electricity/ HVAC/ Water; Building engineering systems: Structural Engineering: Theory and Design; Geodesy/ Surveying; History, theory of Civil engineering, Architecture, Arts; Humanities/ Social Sciences; Mathematics/ Natural sciences; Professional practice courses.

Research, Continuous Professional Development and Teaching Competence

Research: Conduct research, have a scientific investigative attitude, submit articles for scientific journals and magazines; innovate in one’s research area; objectively organize information and results. Following are essential course blocks for the training of the competence: Mathematics/ Natural sciences; Professional practice courses.

5. Conclusions

The appearance and development of AE in the construction field has been stimulated by the need to optimize construction project development, and improve the sometimes inefficient collaboration between the architect and structural engineer.
The essential AE professional skills and knowledge which compose the competence model presented in this paper are based on the analysis of the professional practice of architects and structural engineers, and on the analysis of the competence models for professionals in various science branches.

The undergraduate AE program was developed in relation to the Competence Model. The program courses, transformed into 13 course groups, are presented in the study and linked to particular competences in the model. In further research authors will focus on the fully developed study program presented in details.

References

[1] Larena, A. B., 2006. Origin of the Collaboration between Engineers and Architects in Great Britain in the Thirties [online], [cited 21 January 2013]. Available from Internet: http://www.arct.cam.ac.uk/personal-page/james/ichs/Vol%201%20357-378%20Bernabeu.pdf [2012 02 12]

[2] Do we need architects?, n.d., [online]. Urban realm, 15 Apr 2011 [cited 21 January 2013]. Available from Internet: http://www.urbanrealm.com/features/319/Do_we_need_architects%3F.html [2012 02 22]

[3] Saint, A., 2008. Architect and Engineer: A Study in Sibling Rivalry, Yale University Press. ISBN:10: 0300124430.

[4] Holgate, A., 1992. Aesthetics of built form [online], [cited 21 January 2013]. Oxford University Press. Available from Internet: http://home.vicnet.net.au/~aholgate/structdes/aobf_anchor.html

[5] Jodko, A., 2012. "Architektūra ir konstrukcijos. Studijų ir Praktines veiklos skirtumai", Proceedings of the 15th Conference for Junior Researchers "Science – Future of Lithuania" CONSTRUCTION, 22-24 March, Vilnius, Lithuania. ISBN 978-609-457-215-9 ISSN 2029-7149 online

[6] Bendrasis technologijos mokslų (inžineriøj) studijų sritis reglamentas, 2005 m. balandžio 29 d. Nr. ISAK-734 (Žin., 2005. Nr. 59-2079) [online] [cited 21 January 2013]. Available from Internet: http://www.snp.lt/smt/st_org/docs/st_regl/Technologijos%20akt.pdf

[7] Jodko, A., Parasonis, J., 2012. Curricula of the World Architectural Engineering Undergraduate Programs, International Journal of Engineering Education 28(3), pp. 633–641.

[8] Drexel College AE undergraduate program curriculum [online], [cited 21 January 2013]. Available from Internet: http://catalog.drexel.edu/undergraduate/collegeofengineering/architecturalengineering/#sampleplanofstudybtext

[9] VGTU AE undergraduate program curriculum [online], [cited 21 January 2013]. Available from Internet: https://medeine.vgtu.lt/programos/programa.jsp?fak=2&prog=132&sid=En&kib=En

[10] McGill, B.Sc. (Arch.) Curriculum, 2012 [online], [cited 21 January 2013]. Available from Internet: http://www.bac.rmit.edu.au/undergraduate/courses/curriculum/bscarch.html

[11] Rating Canada's Architecture Schools as Researchers: 2009/13 results [online], [cited 21 January 2013]. Available from Internet: http://www.bac.rmit.edu.au/undergraduate/courses/curriculum/bscarch.html

[12] ETH Zurich – D-BAUG – Curriculum Civil Engineering - Bachelor Degree - Course Overview, 2012 [online], [cited 21 January 2013]. Available from Internet: http://www.bauing.ethz.ch/bachelor/curriculum/index_EN

[13] Top European Engineering Universities, [online], [cited 21 January 2013]. Available from Internet: http://www.topuniversities.com/university-rankings/world-university-rankings/2012/subject-rankings/engineering/civil-engineering