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EXCELLENCE IN BUILDING SCIENCE EDUCATION: EXPERIENCES WITH A CENTRAL EUROPEAN EXPERIMENT

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Abstract. The spectrum of educational programs in building science is wide and diverse. Whereas the academic landscapes across the world vary significantly, general discourse postulates certain rather broad characterizations. For instance, some schools, especially in the Anglo-Saxon context, are suggested to target a selective, private, and high-tuition approach. Others, particularly in the European context, have a more broad, public, and affordable nature. Even though highly simplistic and perhaps even misleading, this distinction has been frequently accompanied by the implicit assumption that true excellence (the so-called world-class) education in general and building science education in particular is possible only in the former settings. In this paper, we report on a specific academic degree program, namely the Master in Building Science and Technology (BST) program, which may be argued to cast doubt on this assumption. Initiated at TU Wien, Austria, BST was offered over a period of almost two decades. In this paper, we briefly present the genesis of this program, its features, its accomplishments, and its termination. Thereby, our primary objective is to inform similar and future initiatives, particularly across Central Europe, where many public universities exist, the building industry has a substantial presence, and the education of a future generation of technically competent, environmentally conscious, and socially responsible building planners and engineers is of essence.

Keywords: Building science, building technology, curriculum development, environmental education, multidisciplinary teaching.

1. Introduction

The construction and operation of buildings have major implications. These include the use of resources (energy, materials), the impact on environment (emissions), and the influence on human health, comfort, and satisfaction (indoor-environmental quality) [1–6]. This observation underlines the importance of the education and preparation of professionals responsible for buildings' design and operation [7, 8]. Due to various reasons, including the inherent complexity and multi-disciplinary nature of the building delivery process [9], this education cannot be limited to a single trade and a single format (such as the one offered by conventional architecture schools). This explains the increasing appearance of multiple building-related educational concentrations at different levels. One such concentration pertains to a specific domain that is variously referred to as building science, building physics, or building performance. Professionals working in this domain are expected to display in-depth understanding and skill in matters related to buildings' technical quality. As such, they must address, among other things, buildings' thermal, visual, acoustic, air quality, fire safety, as well as energy and environmental performance [3, 6, 10–12].

In this context, the present contribution discusses the attributes of and experiences with an educational graduate-level program in Building Science and Technology (BST) area, implemented and operated over a period of 15 years at TU Wien in Austria. Thereby, the primary objective is to inform similar and future initiatives, particularly across Central Europe, where many pertinent academic institutions exist, the building industry has a substantial presence, and the education of a future generation of technically competent, environmentally conscious, and socially responsible building planners and engineers is of essence.

2. Background

The conception and initiation of the BST program was motivated by a number of observations and experiences. Whereas the academic landscapes across the world vary significantly, general discourse postulates certain rather broad characterizations. For instance, some schools, especially in the Anglo-Saxon context, are suggested to target a selective, private, ranking oriented and high-tuition approach, others, particularly in the European context, have a more broad, public, and affordable nature. Even though highly simplistic and perhaps even misleading, this distinction has

been frequently accompanied by the implicit assumption that true excellence (the so-called world-class) education in general and building science education in particular is possible only in the former settings. The initiators of the BST program considered the potential for synthesis of these elements. The idea was that an educational program with high conceptual leaning toward fundamental science foundations can be implemented in a public technical university geared toward industry-driven professional education. Likewise, the idea was that the merit-based admission to the program and continued performance monitoring can be also implemented in a low-tuition public educational setting. Specifically, one of the initiators had experienced in-depth, both the conventional architecture and engineering curricula in German speaking countries and the so-called elite university programs in North America. The idea was to conceive a master program in BST that would appeal to candidates with a diverse background in their undergraduate education, would be open to acquire a deeper theoretical foundation, and engage in intensive learning process concerning digital tools and computational modelling. The selection of English as the program's language facilitated the emergence of an international body of students and made it possible to implement a formal admission procedure for the incoming students.

3. A brief history

The BST program could not be initially started as a "default" master program at TU Wien. This was due to internal circumstances in the pertinent college (Faculty of Architecture and Planning). There were concerns on the side of the senior staff that resources would be diverted from the Architecture program to a new program whose nature and necessity they may have insufficiently realized. On the other side, some representatives of the student body were opposed to introduction of admission conditions and processes intended by the initiators of BST. Note that the majority of the disciplines at TU Wien do not require any admission requirements other than high school degree. However, a program offered exclusively in English (as opposed to German) could be exempted from this practice, a circumstance that the BST initiators intended to use so as to define necessary conditions for admission to the program. As the result of these oppositions, the program had to be initially installed as a post-graduate master program within the TU's continued education framework, which is not tuition-free and is mainly meant for professionals seeking a flexible educational opportunity while remaining active in their jobs. During this phase, the program included three foci, namely building physics, structural design, and design computing.

In the framework of two delivered cohorts this program educated a number of well-qualified graduates. However, the circumstances were not seen as ideal in view of the program initiators. On the one hand, the more desirable access rules (i.e., no or a very small tuition) available to TU's regular programs was not available for BST students. On the other hand, the operation of the program with three parallel foci (building physics, design computing, structural design) was not found to be the most efficient solution, implying the need for further topical concentration. Benefiting from a window of administrative opportunity, it was possible to move the BST to the regular educational program. Subsequently, the curriculum was also modified to provide a more robust focus on building physics. From this time on, the BST was offered as a regular 2-year master program until its discontinuation in the year 2021. The reasons for program's termination were not inherent to the academic nature of the program, which has been shown to be very successful. Rather, top-down decisions at the higher level of TU governance ultimately led to circumstances that made the termination of the program inevitable (see Section 5 for further details on the circumstances responsible for this development).

4. The structure of the curriculum

As indicated before, the BST curriculum experienced a larger revision (augmented concentration on building physics content accompanied by computational and diagnostics tools and methods) and a few smaller adjustments. The result of these development was a fairly stable, robust, and efficient curriculum. The syntax and content of this curriculum are presented in Figure 1 in a compact form.

In terms of the course load, the curriculum has the Bologna-conform 4-semester 120 ECTS format [13]. Following a university-mandated overall curricular framework, the entailed courses in the programme (see Figure 1 for details) are structured in terms of thematically coherent groups referred to as modules. The general sequential logic of the program corresponds to the envisioned students' progression in knowledge and skills acquisition. Focus on foundational material in the first semester, intensification of disciplinary material in the second semester, the multi-disciplinary, collaborative and praxis-oriented project course in the third semester, and the individual research work in term of the final semester's master thesis was intended to offer the right superposition of program syntax and the program content.

5. Experiences with the operation

The long-term multi-year experience with the BST program involved on the one hand highly positive aspects, but also a number of challenges. To start with the positive, a few observations are listed below outlining the key contributing factors to the program's success:

- The aforementioned decision pertaining to the introduction of admission requirements for BST pro-

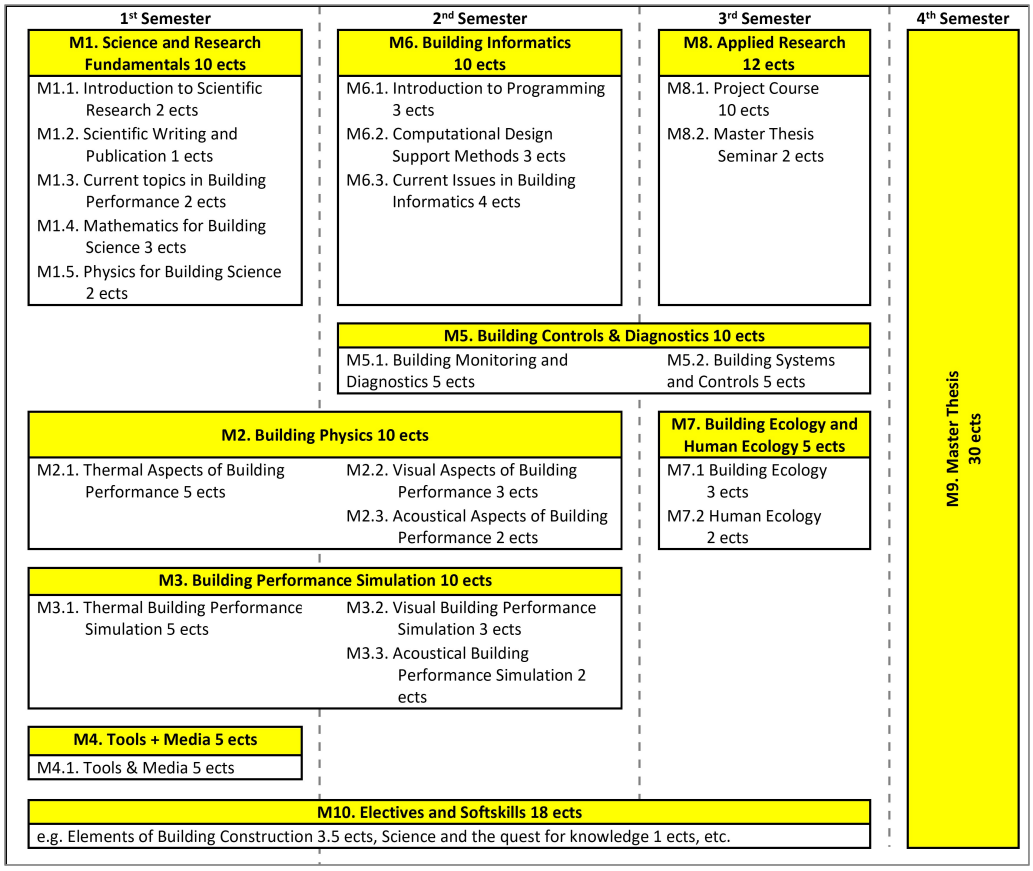

Figure 1. Structure of the BST curriculum.

gram made it possible to maintain, in comparison to other (bachelor and master) programs of the college, a smaller student to teacher ratio.

- English as the language of the BST program may have encouraged a more diverse (internationally oriented) body of students, which is arguably less common in Central European programs.
- The disciplinary diversity of the backgrounds of the students (architecture, engineering, computing) supported the emergence of an inquisitive and open-minded attitude within the student body. This sharpened also the understanding and appreciation of the interdisciplinary and collaborative aspects of the building design and delivery process.
- The foundational courses in mathematics, physics, and computing made it possible to bring up the students with background in architecture to the necessary prerequisite levels of students with backgrounds in engineering and informatics. On the other hand, courses regarding tools and media, as well as a specifically tailored building construction course introduced students with engineering and informatics background to the building technology skills and knowledge.
- Early focus on courses that dealt with the scientific method supported the development of a better grasp of the nature of scientific research. This contributed also to students' preparations for their master thesis.
- A pair of BST attributes, one regarding the orientation and the other regarding the approach may have contributed to its success and reputation. The former attribute pertains to a parallel emphasis on both theory (scientific foundations) and praxis (applied skills). The latter attribute is related to the concurrent application of both computational and experimental tools and methods.
- A major course in the third semester of the program, namely the "project course" was found to be especially effective. This course was not focused on frontal transfer of knowledge. Rather, it regularly selected practically relevant research and/or planning agenda regarding the quality and performance of the built environment as its subject. Students worked collectively and in teams on the task at hand, thereby assuming various roles (e.g., building design, system configuration, performance modeling).
- A few courses emerged in a kind of evolutionary step based on experiences gained in the early years of the program. One course, labeled "Master Thesis Seminar" accompanied the students in the preparation of their master thesis proposal. Earlier experiences had shown that completing a high-quality master thesis in the final semester of the studies was not a trivial matter. The seminar facilitated, in the

preceding semester, the initial consideration of possible topics, their merits, and the feasibility of their completion. Thereby, the students could select the topic of their thesis themselves, or request the supervisor for suggestions. Another course, the "Master Progress Seminar", accompanied the students in the actual developmental work for their master thesis. Thereby, the students could attend the progress presentations of their colleagues, receive feed back from the supervisors, and discuss their work with the other students.

- The general sequential logic of the program fulfilled the expectations with regard to the students' progression in knowledge and skills acquisition. Focus on foundational material in the first semester, intensification of disciplinary material in the second semester, the multi-disciplinary, collaborative and praxis-oriented project course in the third semester, and the individual research work in term of the final semester's master thesis proved to offer the right superposition of program syntax and the program content.
- The generally research-oriented master thesis in the final semester of the program did serve multiple purposes. Aside from acting as final exercise in independent structured query, the master thesis enabled the students to pursue, in an in-depth manner, subjects that they considered to be essential in view of their future plans and aspirations. Frequently, the research conducted in the framework of the master thesis provided the students material for scientific publications in conference proceedings and journals, hence improving their career chances for those targeting future academic employment opportunities.
- Upon completion of their master studies, a considerable number of graduates decided to pursue doctoral studies both at TU's Department of Building Physics and Building Ecology and in other schools.

As alluded to before, the program faced also a number of challenges with regard to both academic performance and administrative boundary conditions. Instances of such challenges are briefly addressed in the following:

- Given the students' non-homogeneous backgrounds and differences in their skill levels, the knowledge transfer process could not be maintained in a consistently optimal manner. Hence, in a few occasions, the learning material and the knowledge transfer pace was turned out to be too advanced for some students and insufficiently challenging for others.
- The BST master degree was conceived as a full-time educational program. Nonetheless, due to the absence of stipends and despite the low tuition level, a fraction of (self-supported) students needed to work on the side. This resulted, in certain cases, in scheduling frictions, reduced level of concentration, and ultimately a lengthened duration of studies.
- The role, value, and accomplishments of the BST program were perhaps insufficiently visible at the college and university level. The lack of precedence for such a pioneering internationally oriented building science program offered exclusively in English language may have contributed to this circumstance. As perceived by the program initiators and staff, the most critical challenge faced by the program, was the insufficient level of engagement (structural and institutional support) from the college and university instances. Consequently, the program could be offered over the course of multiple years only due to the sheer dedication and ultimately self-exploitation of the involved faculty. Every aspect of the program had to be taken care of exclusively by the immediate BST staff (predominantly members of the Building Physics and Building Ecology Department), who had also many other responsibilities (teaching in bachelor and master programs in Architecture, supervision of doctoral studies, academic research). Moreover, processes regarding the promotion of the program, the students' admission process, the curriculum design, the scheduling and offering of the courses, the evaluation of students' performance, and the dissemination of students' research did not benefit from college or university support.
- The absence of a promotional budget made it difficult to make the programme broadly known. This probably reduced the pool of potential applicants. Moreover, university's position in international ranking schemes (a factor amongst those influencing candidates' choices of schools), the absence of stipend offers, and the impression that studying would require the knowledge of German language, might have led some very talented students to seek admission in other universities.

6. Performance and output

The objective presentation and evaluation of the standing and performance of an academic program is not a trivial matter. Nonetheless, some factual data and statistics related to the BST program's educational and academic output may offer a measure of performance accessible to some degree of objective scrutiny.

Since the inception of BST in the year 2004, roughly 160 students (57 % female and 43 % male) graduated from the program with a master in BST (as of September 2021). Figure 2 illustrates the distribution of the topical foci of the master thesis of the graduated students.

The median duration of the studies amounted to 6 semesters. This is longer than the 4-semester duration intended by the program initiators. However, as mentioned before, a number of students worked part-time, hence requiring more time to complete their studies.

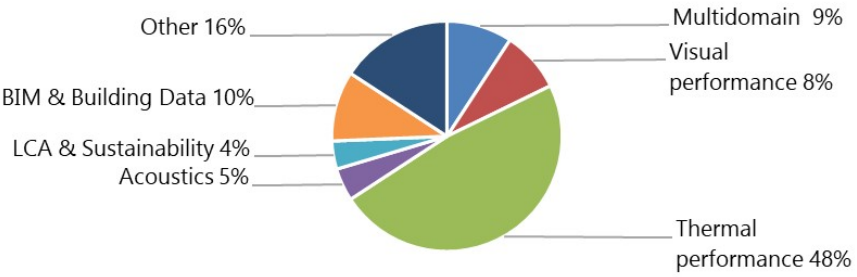

Figure 2. Topical distribution of the BST graduates' master theses.

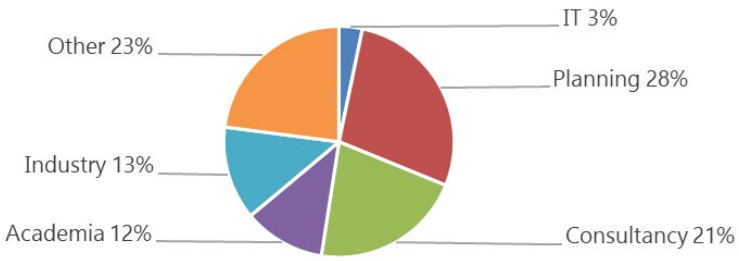

Figure 3. Survey results concerning past BST students' professional foci after their graduations.

Aside from the master theses themselves, related publications represent another measure of the academic output of the BST program. Altogether, 91 conference papers and 29 journal papers were co-authored by the BST students. The distribution of the thematic foci of these publications corresponds roughly to that of the completed master theses (see Figure 2).

The performance and ultimately the real-world success of the BST program can be also approached based on the carriers pursued by the graduates. Upon completion of their master studies, 18 students pursed doctoral studies at the Department of Building Physics and Building Ecology or, in a few cases, other units of TU Wien. Due to certain constraints (specifically with regard to data privacy issues), it is not possible to put together a comprehensive record of the activities and carriers of the BST students after their graduation. However, a recently conducted survey among the BST's program's graduates resulted in 61 responses. The processing of the data obtained via this survey yields an overview regarding the professional careers the BST students pursued subsequent to their graduation (see Figure 3).

In the course of the survey, impressions, opinions, observations, and ideas were solicited as well. The responses were positive in general. A few instances of this feedback (statements in the survey) are included in the following:

- "The Master Program was first of all a professional boost in my career and a socially fulfilling experience – I have enjoyed having an international team of lecturers as well as group colleagues not only from various cultural, but also professional backgrounds."
- "The multicultural and interdisciplinary environment of the program was very interesting and widened my horizons both intellectually and professionally and for that I'd be always grateful."
- "I found very necessary in the job market the digital tools I learned at the TU Vienna. I would recommend more advanced ... courses ... during master studies. Energy certifications are also very demanded in the market, emphasis should be given into that too."
- "I personally found the pace of studies a bit slower than I expected ... For example ..., the CFD analysis also could have lasted a whole semester."
- "[The] master study ... had a very good quality of education and opened several career doors to its graduates!"

7. Lessons learnt

The complex background of the BST program and the rich set of experiences with its operation cannot be summarized in terms of a few observations. However, some qualitative reflections, structured in terms of a kind of brief SWOT analysis (strengths, weaknesses, opportunities, and threats), may provide some insights that could be of use for similar initiatives in the future.

- Strengths: As alluded to before, the major strengths of the program lie in its combination of scientific foundations, digital media, diagnostics skills, balance between theoretical models and practical applications, balance between mandatory and elective courses, and last but not least, the vibrant multicultural composition of the student body.

- Weaknesses: BST was intentionally open to applicants from different educational backgrounds. This had advantages (for instance, in the operation of the project course and its real-world collaborative agenda). However, this diversity represented also a challenge in view of the optimal depth and sophistication of material coverage. But the most critical challenge the program faced was perhaps not an endogenous one. Rather, it was mainly due to the boundary conditions. For an academic program to be sustained over the long haul, the institutional understanding and support is essential. Of course, an inspired educational initiative requires, as the necessary condition, the "bottom-up" engagement and enthusiasm of the involved faculty. This is, however, not sufficient in the long run, as the BST experience clearly demonstrates. Institutional support is essential, both in administrative terms (promotion, admission, service, tuition and stipend options) and the academic sense (faculty positions and time).
- Opportunities: As BST no longer exists, the discussion of opportunities is relevant only to future efforts. Many Central European technical universities have an excellent background in engineering education. Extending their repertoire with novel computationally driven and interdisciplinary programs does not negate this excellence. Rather, it facilitates the transition to creative academic offerings of the future. Moreover, adaptation of certain strategies in the graduate programs of the so-called top universities does not mean that one must also adopt their so-called elitist features (highly restrictive admission procedures and exorbitant tuitions).
- Threats: Again, the termination of the BST program makes the discussion of the threats relevant only in view of possible future initiatives. A general threat, not only related to BST, but to most academic programs, concerns the rapid developments in the so-called information society. Recent trends with home-officing and online-teaching have been used as arguments to question the future feasibility and viability of the "traditional" academic programs. There is no reason why new forms of digitally supported and hybrid methods and platforms of knowledge transfer and life-long learning should not be adopted. But the related processes need to be careful not to throw the baby of empathic learning environments with the bath water of conventional frontal classroom teaching. Specifically, the design and operation of built environment is an inherently collaborative and contact-intensive process. Care should be thus taken that future developments in academic formats would not neglect this essentially communal attribute of the building delivery process.

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