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Leveraging international academic partnerships for the design of a collaborative sustainability-focused graduate civil engineering program

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1. Introduction

Within this paper, the authors detail the design of a joint, graduate-level program (herein, referred to as the Program) in civil engineering, entitled Sustainability Engineering for the Built Environment. The Program is the result of an international collaborative effort between the Department of Engineering and Engineering Technology (EAET) at Metropolitan State University of Denver (MSU Denver) and the Faculty of Engineering and Information Technology (FEIT) at the University of Pécs (UP). A full description of the Program is provided followed by a detailed recount of the design process.

1.1 Background

1.1.1 Universities

MSU Denver is a primarily undergraduate university that has been classified as both a minority-serving and Hispanic-serving institution since 2019. The University has an open enrollment policy and specializes in non-traditional (e.g., average student age is 25), first-generation (e.g., 57% of the student body), and veteran education. The University primarily serves the Denver community, where approximately 96% of the student body is from Colorado with the vast majority coming from the surrounding counties. Additionally, EAET offers both bachelor's degrees and undergraduate certificate programs.

The University of Pécs (UP) is the oldest university in Hungary and was originally founded in 1367. The University consists of 10 faculties including economics, medicine, law, and art. More than 20,000 students attend the university and approximately 4,500 are international students. The FEIT offers several undergraduate and postgraduate (e.g., MSc, specialist training, and DLA) programs in architecture, computer science, and engineering in both Hungarian and English. There are approximately 3,000 students in the FEIT of which approximately 700 are international students.

1.1.2 Collaboration history

The University of Pécs and MSU Denver have a long and successful history of collaboration (since 2010) in the fields of architecture and civil engineering. This includes several jointly taught subjects dealing with architecture, structural engineering, sustainability, and humanitarian engineering. Some highlights include:

- MSU Denver study abroad course entitled Refurbishment of Structures hosted by UP in 2010
- First UP visiting professor instructing at MSU Denver in 2011
- English immersion program at MSU Denver in support of the Master's in Architecture English-language program at UP in 2013

- Collaborative development of an Architecture Minor at MSU Denver from 2013 through 2015
- English immersion program for UP engineering faculty at MSU Denver in 2016
- Collaborative Research on "Laboratory Testing of Timber-Concrete Composites Adaptable Architecture" from 2013 through present
- UP faculty teach engineering and architecture courses at MSU Denver starting in 2014 through present

1.1.3 Related sustainability initiatives

Over the last decade, the UP and FEIT have introduced concepts of sustainability into the curriculum [1], and concurrently, MSU Denver has likewise developed and initiated the Sustainable Systems Engineering undergraduate program [2]. However, even with these initiatives, there remains a demand for graduate education that provides a holistic view of sustainability of the built environment across multiple disciplines.

The arrival of the pandemic and the subsequent transition to online teaching, ironically, provided the opportunity for greater collaboration in teaching between MSU Denver EAET and UP FEIT, as well as, in some cases, Brunel University London and Dortmund University of Applied Sciences and Arts. Two different collaborative courses were held over four semesters with lecturers from the four universities. One of these courses, the International Engineering Project, was based on the Engineering Design Challenge organized by Engineers without Borders UK. Students from a variety of majors (e.g., architecture, civil engineering, IT, electrical engineering, mechanical engineering, environmental engineering, sustainable systems engineering) worked in cross-university and cross-discipline groups to solve design challenges for two low-income communities in Peru, and in the following year, a disadvantaged community in Cape York, Australia. The second collaborative course which also ran for two semesters was on Sustainability in Structures. The course was initially open only to MSc structural engineering students but was later expanded to include MSc architectural design students at UP, and civil, environmental, and sustainable systems engineering BS students at MSU Denver. Students collaborated in groups to design a fire lookout tower in the first year and a short span pedestrian bridge in the following year. In summary, the resounding success of the previous collaborative efforts stimulated the proposal for a joint multidisciplinary program related to sustainability in engineering.

1.1.4 Similar programs

The authors acknowledge the wealth of existing information related to the design of a joint international graduate program for civil engineers that focuses on sustainable engineering. Some similar programs include domestic graduate-level sustainable engineering programs [3]–[5], international undergraduate study abroad experiences in sustainable development [6]–[8], and collaborative international graduate engineering programs [9]–[11]. Additionally, the authors desire that their paper will further inspire joint international initiatives for global sustainable development education.

1.2 Motivation

The motivation for the development of the Program can be subdivided into the perspectives of students, the university and department/faculty, and global society.

1.2.1 Student perspective

First, the Program will allow for numerous benefits for both MSU Denver and UP students. Benefits include, 1) allowing students to target jobs with a sustainability focus, which is a currently in-demand career path, 2) offering students both regional and international perspectives on civil engineering, sustainability, and culture among others, and 3) providing access to international experts in the field of built environment sustainability.

1.2.2 University and Departmental/Faculty perspective

A graduate program also allows for some of the following benefits to the universities and the department/faculty such as, 1) increased student enrollment, which has been steadily declining since the onset of the COVID pandemic, 2) heightened program relevancy [12], 3) strengthening of the international partnership, 4) advancement of sustainability initiatives of all constituencies, and 5) progression of MSU Denver's visibility as a leader in sustainability engineering in Colorado and likewise UP in Hungary.

1.2.3 Global perspective

Furthermore, as educators, it is our responsibility to educate our students on current global sustainability initiatives and the practices and methodologies for implementing those initiatives. Civil infrastructure and the construction industry has a massive impact on our environment. According to the UN, buildings are currently responsible for over 40% of global energy related carbon emissions and 50% of all extracted materials, and additionally, global building stock is expected to double by 2060 as a result of a growing population and urbanization [13], [14]. As such, engineers have a critical and necessary role in advancing the fairness and sustainability of our society. More so, civil engineers are in a timely position to expand upon the conventional paradigm of solely providing for our current society, to explicitly consider the needs and demands of future generations. In particular, it is vital that the infrastructure-related (e.g., design, construction, management) industry in Colorado has the capacity and capability to enact climate change mitigation strategies and to contribute to reducing energy dependencies. One essential component in building that capacity and capability is educating the workforce. The Sustainability Engineering for the Built Environment graduate program can provide the necessary multidisciplinary knowledge to provide these needs.

2. Program

2.1 Program details

General Program details are displayed in Table 1. The key distinction between both university offerings is the educational credential and the associated credit requirements. While MSU Denver plans to offer a graduate certificate requiring 15 semester credit hours (SCH), UP will offer a Postgraduate Specialist Training credential requiring 60 European Credit Transfer and

Accumulation System (ECTS) credits, which is equivalent to 30 SCHs. Additionally, lectures will be conducted in either in an online synchronous or hybrid format and will be delivered in the afternoon hours in Pécs and the morning hours in Denver.

Table 1. Program Details

Program Title	Sustainability Engineering for the Built Environment
Educational Credential	Graduate Certificate (MSU Denver) Postgraduate Specialist Training (UP)
Required Credits	15 Semester Credit Hours (MSU Denver) 60 European Credit Transfer and Accumulation System (UP)
Duration	2 semesters
Course Delivery Mode	Hybrid/Online Synchronous
Language	English

2.2 Program description

The Program in Sustainability Engineering for the Built Environment is focused on the integration of sustainable development goals in the design, construction, and enhancement of civil infrastructure systems. This graduate certificate is well suited for current engineers with a desire to advance their education, for recent graduates with an interest in developing skills beyond their field of specialization, and for students seeking a more holistic view on balancing engineering solutions with societal needs of both today and the future.

To achieve the desired outcomes, the Program offers students a multidisciplinary and robust curriculum on sustainability engineering for the built environment. The individual modules span topics including sustainability, sustainable construction technologies, environmental sustainability, refurbishment of structures, sustainable cities, and optionally, a thesis opportunity. In culmination, the graduates of the Program will be able to utilize their unique skillset (e.g., critical thinking, design, management, leadership) to not only engineer challenging infrastructure solutions but to also strategically incorporate economic, environmental, and societal objectives for a comprehensive sustainable design. It is expected that those who graduate from the Program will be well prepared for the increasingly important and necessary task of incorporating sustainability initiatives in the civil design and construction sectors.

2.3 Curriculum

The curriculum for the Program is organized (Table 2) into five primary modules, which are sustainability engineering, sustainable construction technologies, environmental sustainability, refurbishment of structures, and sustainable cities, and a sixth module, a thesis, which is unique to UP. At UP, each module contains two courses, whereas at MSU Denver, each module consists of only a single course; however, the main course in each primary module will be shared amongst both universities. For example, within the first module, CIVE 5100: Sustainability Engineering at MSU Denver and Fundamentals of Sustainability at UP are the same course. Additionally, the number of credits per course are documented either in semester credits hours for MSU Denver or ECTS credits for UP. Furthermore, certain courses are planned to be jointly taught by both universities, while others will be instructed by a sole university.

Table 2. Proposed Joint Program Curriculum

Modules		Courses				Allocation
No.	Title	MSU Denver	SCH	UP	ECTS	
1	Sustainability Engineering	CIVE 5100: Sustainability Engineering	3	Fundamentals of Sustainability	6	Joint
				Case Studies	4	UP
2	Sustainable Construction Technologies	CIVE 5400: Sustainable Structures	3	Sustainable Structures, Construction Materials, and Technologies	6	UP
				Adaptable Architecture	5	UP
3	Environmental Sustainability	CIVE 5300: Environmental Impact Assessment	3	Environmental Impact Assessment	4	MSU Denver
				Waste, Energy, and Water Management	5	UP
4	Refurbishment of Structures	CIVE 5500: Refurbishment of Structures	3	Condition Assessment and Structural Repair of Buildings	5	Joint
				Laboratory: Testing of Materials and Structures	4	UP
5	Sustainable Cities	CIVE 5200: Sustainable Urban Environment	3	Sustainable Urban Envrionment	5	Joint
				Building Energy Performance	6	UP
6	Thesis			Thesis Prepatory	4	UP
				Thesis	6	UP
			∑=15		∑=60	

2.3.1 Course descriptions

Course descriptions are documented per module.

Module 1: Sustainability Engineering / Fundamentals of Sustainability

The United Nations Brundtland Report defines sustainability as “meeting the needs of the present without compromising the needs of future generations to meet their own needs”. This course introduces students to different aspects of sustainability and the growing need for a sustainable mindset, especially for those who would like a career in engineering. Topics such as limits to growth, environmental ethics, climate change, Sustainable Development Goals (SDGs), and the circular economy, will form the foundational knowledge for more advanced topics in sustainability and the built environment in subsequent modules. This course also introduces the principles and techniques for the synergistic design, integration, and management of complex systems over their entire life cycle.

Module 1: Case Studies

In real-world projects, it is not always possible to isolate different actions as neatly as in a teaching environment. In reality, there are always interactions between stakeholders and actors,

and there are different approaches for dealing with them. The case studies in this course will help students understand the needs of different stakeholders and create a list of priorities that will enable them to achieve project goals in practice. The course will also cover the integrated design process (IDP), which is a specific tool and approach for holistic and systemic design thinking. For the success of a complex, sustainable built environment project, which could involve hundreds or even thousands of actors, it is necessary to have a clear understanding of the market in which the designer is operating. Therefore, the course will address questions such as "What are the goals and interests of different stakeholders?", "What is the role of an IDP coordinator?", "How do you frame a workshop?", and "How do you set up and clarify the goals of a meeting where you want to engage diverse stakeholders?". Based on real case studies students get the opportunity to practice these skills.

Module 2: Sustainable Structures / Sustainable Structures, Construction Materials, and Technologies

Students are introduced to various sustainable construction materials and technologies that are resource efficient and minimize impacts on the environment. This course is subdivided into two main themes: Sustainable Structures and Construction Technologies and Sustainable Construction Materials. Within the first theme, the course will cover topics such as sustainable concepts in structural design, functional and structural lifespans, design for extended service life, design for optimized end of life solutions, structural optimization based on minimizing CO_2 emissions, life-cycle management of structures, 3D printing technology in construction industry, modularity and prefabrication in sustainable architecture, designing for adaptability and deconstruction, and optimization of the construction process with the use of Building Information Modelling (BIM). Within the second theme, students will be introduced to high-performance structural materials, natural materials, biomimicry in construction materials, nanotechnology in construction materials, recycling of construction materials, sustainability-driven material choices (e.g., durability, life-cycle cost, low carbon footprint, resilience, etc.).

Module 2: Adaptable Architecture

This course introduces human-centered and future-proof design with a focus on enhancing adaptability and resilience while prioritizing personal comfort. The goal of human-centered and future-proof design is to reduce negative impacts on the environment and improve the health and comfort of building users. This integrated, holistic approach supports finding sustainable solutions to problems without compromise and affects all stages of a building's life cycle, including design, construction, operation, and decommissioning. This approach can contribute to the creation of an adaptable and resilient built and social environment that enhances health and well-being. In this context, students can learn about multidisciplinary design methods for creating sustainable indoor environments. This course offers a collaborative learning experience where students can understand the importance of collaboration among different disciplines beyond engineering to broaden their understanding of design and practice.

Module 3: Environmental Impact Assessment

With any construction project or development there are likely to be environmental impacts. With the rise of environmental pollution and its numerous ramifications, the importance of preserving and remediating the environment around us is unavoidable. This course provides an introductory background into environmental protection (EP), Environmental Impact Assessment (EIA), and Life Cycle Assessment (LCA).

Module 3: Waste, Energy, and Water Management

This course focuses on the sustainable management of solid waste, energy, and water resources, which is a necessity for healthy communities: management. Within waste management, the primary topics include defining waste, trends in waste management, the waste management hierarchy, waste collection and processing, and the lifecycle of a landfill. Global demand for energy has significant environmental implications, and renewable energy is just one part of a broader energy strategy. Topics pertaining to energy management include energy technologies, renewable energy, energy performance and auditing, and energy strategies from a macro-economic and sustainability viewpoint. The content pertaining to sustainable water management includes ecological water management systems for building, wastewater and stormwater quality, rainwater and greywater treatment and utilization, alternatives to black water treatment, green roofs in water management, heat and electricity generation from wastewater, and hydropower electric generation.

Module 4: Refurbishment of Structures / Condition Assessment and Structural Repair of Buildings

Although the construction of new buildings and structures often attracts more attention in both the news and in education, it is the renovation, refurbishment, and strengthening of existing building stock and structures that is often more important from a sustainability point of view. Students are introduced to methods for assessing the structural condition of structures as well as suitable structural repair strategies. Structural assessment topics include deterioration of materials and structures, material testing, destructive testing, non-destructive testing of structures, structural health monitoring, smart monitoring system, analysis methods, and risk assessment. Topics related to structural repair include the principles of rehabilitation, repairs, strengthening, maintenance, and deconstruction, repair solutions for prolonged service life, strengthening for improved safety and resilience, strengthening of concrete, steel, and timber structures, and rehabilitation of historical structures.

Module 4: Laboratory: Testing of Materials and Structures

In this course, building construction elements and materials will be tested using different tests methods. The laboratory tests will focus on non-destructive diagnostic and condition monitoring methods, with particular attention to the possibilities of combined application of these methods. During the practical sessions, students will have the opportunity to learn how to apply the test methods to specific survey tasks. The test methods used will include, among others, various point cloud-based geometry surveys, non-destructive surface strength testing procedures, tomographic non-destructive imaging procedures, and chemical tests to determine the degradation processes of building materials.

Module 5: Sustainable Urban Environment

In this course students are introduced to the interpretation of sustainable urban development, design and planning studies, based on advanced global approaches. The course discusses the factors and elements shaping cities over time, including historical and contemporary issues. Also presented are a variety of solutions in urban environments from around the globe.

Module 5: Building Energy Performance

Since the rapid development of computational modelling, it is possible to evaluate the behavior of highly complex systems such as the energy performance of buildings, neighborhoods, and cities. The course will teach students the fundamentals of climate and microclimate impacts, building physics, basic HVAC systems, and urban climatology such as the heat island effect and its influence on and the building stock. These fundamentals will help students to learn to evaluate the different scales of energy performance of the built environment. For optimized energy performance at various scales, passive and active systems could be used. These could be evaluated with the help of simple calculations and with more complex computational methods. The course's goal is not only to introduce the tools of these energy-related interactions but also to let students understand the output of performance modelling tools, which is a necessity to master optimal sustainable design.

Module 6: Thesis Preparatory

Thesis Preparation is a course designed to guide graduate students through the process of researching and writing their thesis. The course will cover topics such as selecting a topic, developing a research question, conducting literature reviews, designing and implementing research methods, analyzing data, and writing and revising the thesis. Throughout the course, students will receive feedback on their work and guidance on how to improve their research and writing skills. The course will also discuss the problems facing those who are not native speakers of English and what strategies they can use to overcome this challenge.

Module 6: Thesis

In the culmination of this Specialization/Graduate Certificate, students are tasked to research and write a thesis concerning the application of sustainability engineering techniques to a relevant problem faced by the built environment. Students will first work with the supervisor to identify a project and detail a research methodology. This will be followed by a thorough literature review to identify the current status of the selected project, and an analytical, numerical, and/or experimental study to further elucidate the problem and/or investigate a potential solution. Students will present their findings and conclusions in a written thesis and oral presentation.

2.4 Accreditation process

The proposed programs will be accredited independently according to their respective governmental requirements.

At MSU Denver, it is the responsibility of the Board of Trustees (BOT) to review and approve new certificate programs. Once the BOT approval is obtained, approval requests are submitted to external review levels, such as the Colorado Department of Higher Education (CDHE) and the Colorado Commission on Higher Education (CCHE). Although certificate programs are not reviewed formally, they may be reported to CDHE for entry into their data collection portal (i.e., SURDS). Commission approval must be obtained before requesting approval at the regional level from the Higher Learning Commission (HLC). The HLC assures that the university provides quality education, and the accreditation certifies this assurance.

The Hungarian accreditation process for new university study programs is overseen by the National Accreditation Committee (MAB) of Hungary. The process is designed to ensure that new programs meet the standards and requirements set by the government and are in line with the European Qualifications Framework (EQF), the Hungarian Qualification Framework (HuQF) and the Standards and Guidelines for Quality Assurance in the European Higher Education Area (ESG). For a new tertiary education program, the higher education institution submits a proposal to the Educational Authority, which includes information on the program's goals, structure, curriculum, and resources. The Educational Authority invites MAB to prepare an expert's opinion on the proposal according to ESG2015 guidelines, which includes conducting a review of the curriculum, faculty, facilities, and resources as well as an assessment of the institution's overall ability to deliver the program. If the program meets the required standards, the Educational Authority grants accreditation. Once a program is accredited, MAB may monitor the program on the request of the education authority or institution to ensure that the program continues to meet the required standards.

3. Design process

3.1 Rationale

Within this section, the authors will provide the rationale for specific Program decisions.

The idea for a *joint international* program was the first and most obvious decision in the design process. Based on the numerous collaborative accomplishments, both institutions sought to strengthen the partnership and to leverage past successes to strive for a more prominent goal. Even more, the authors desired to take advantage of the specializations in teaching and research as well as resources at each other's universities. In addition, an international program inherently possesses diversity of individuals and ideas, which is critical for creativity and innovation within academia and society in general. More so, student's will be immersed in this international environment, which often begets positive personal growth and changes in worldviews as well as offers engineers a global perspective on problem solving.

A *graduate* program was decided upon based on economics, educational rigor, and industry standards. First of all, a graduate-level program is the most economically advantageous mode for both universities. In addition, while preliminary sustainability concepts are introduced into the undergraduate civil engineering, at the graduate level, instructors are able to provide students with a significant increase in both breadth and depth of concepts at the graduate level, which

ultimately better prepares students for sustainability-related careers. Furthermore, the Program designers recognize that industry sustainability divisions often dictate that employees have an undergraduate engineering degree in addition to relevant discipline experience before entry into such division. As such, a postgraduate credential offers students a competitive advantage when seeking such a position.

The decision to devise a *sustainability-focused* program was in full recognition of the importance of establishing and pursuing sustainable development goals related to the built environment and educating the future workforce on more sustainable civil engineering practices. In addition, sustainability engineering requires a more holistic, systems approach to engineering design and implementation that is a strong asset for the developing engineers.

For the MSU Denver counterparts, the idea for a *graduate certificate* was conceived as means to realize the long-term vision of the EAET Department, which is to initiate a graduate program. Currently, no graduate engineering credentials are offered at MSU Denver, and in addition, the process for initiating a graduate program is internally competitive. As such, the Program designers believe that the creation of a graduate certificate is perhaps the most auspicious methods to obtain our goal.

For the UP colleagues, the formation of a *Postgraduate Specialized Training* followed the path of least resistance and was the most effective way of beginning an international program focusing on sustainability.

Course selection was the most challenging part of the design process and required multiple iterations. The authors attempted to maximize resources, such as faculty expertise, already established courses, and administration, while being subject to university constraints, such as required credits per graduate credential, funding, and faculty workload. In the end, the planned curriculum is an amalgamation of current and to-be-modified courses that contain the most pertinent topics in the field of sustainable civil design and construction.

3.2 Challenges and benefits

The challenges and benefits encountered during the development of the Program can be broadly categorized into collaboration-specific and Program-specific components.

3.2.1 Collaboration

One immediate challenge hindering the ease of collaboration was the location and time difference (i.e., 8 hours). As such, virtual meetings were held on a regular basis in the morning hours in Denver and afternoon hours in Pécs. Another inhibitor was the communication and understanding of the differing constraints on the credential faced at the two universities; it was one of most critical though trying parts of the design process. For example, managing the differences and equivalencies in course credits as well as instructor contact hours was crucial to properly establishing the curriculum for the joint Program.

Without a doubt, the biggest benefit of the international collaboration in all stages of the Program development was the diversity of ideas, perspectives, and approaches. In addition, all participants gained a thorough knowledge of differing US and EU requirements on higher education.

3.2.2 Program design

Program-specific challenges and benefits can be further divided into those of the university, department/faculty, and the students. In regard to the universities, the MSU Denver colleagues faced immediate adversity in their proposition for the graduate certificate, primarily due to internal competition for departmental graduate programs. On the other hand, the UP counterparts have maintained strong support from the upper leadership in the development of their postgraduate specialized training credential. Additionally, as referenced previously, the constraints enforced by the university on course credits and contact hours had a significant impact on the developed curriculum.

With regards to the EAET Department and FEIT, both groups encountered no obvious challenges. However, one of the compelling benefits of developing a joint university program is the development of a faculty pool for course offerings, which adds a significant amount of resilience to both departments. In addition, a faculty pool allows for the optimization of faculty expertise to generate the highest quality product for students.

Finally, students at both universities stand to gain significant advantages from completion of the Program, such as diversity of thought and perspective, knowledge of both regional and international practices, instruction from discipline experts, and sustainability-focused training. Potential downsides of the Program could be gradual disinterest with a remote course and communication issues due to language differences.

3.3 Work-in-progress

At the point of writing this paper, the initiative to develop the Program is a work-in-progress. UP has submitted their proposal to form the Postgraduate Specialized Training credential, with an anticipated start date of September 2023. Conversely, MSU Denver is finalizing the proposal budget and anticipates a start date of Fall 2024. As such, minor changes to the course offerings comprising the curriculum will incur as UP proceeds without MSU Denver for the first year at minimum.

4. Conclusion

The design of a joint international graduate sustainability program for civil engineers is documented followed by the rationale of the decision-making process as well as the challenges and benefits that were encountered along the way. The Program is currently a work-in-progress as of writing this document, but the authors are confident in its eventual success. Additionally, the Program reflects a further evolution in the partnership between the two involved universities.

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