Sustainability-Focused Integrated Civil Engineering Research and Education

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Abstract: The built environment and construction industry has a huge impact on the usage of the worlds resources, and tertiary education has a major role to play in training engineers who consider different aspects of sustainability in their studies and future work. The purpose of this paper is to explore the importance of sustainability in tertiary education and the initiatives that a university can take to integrate sustainability into its teaching programmes and research. The paper argues that universities have a critical role to play in creating a sustainable future and describes some courses and programmes that the University of Pécs has implemented in incorporating sustainability into the curriculum. It also details the role that international collaboration can play in education, especially when applying an integrated project-based learning approach to solve real world problems. The paper then outlines several research activities that it carries out and the relevance to sustainability, such as recycling concrete, 3D printing and smart monitoring of structures, and how it is important to include students and industrial partners in research. The paper concludes that by embracing sustainability, universities can not only play a crucial role in addressing the environmental challenges of our time, but also help create a more equitable and just world for future generations.

1 INTRODUCTION

It is clear that the built environment and construction industry has a massive impact on our environment. According to the World Green Building Council, buildings are currently responsible for over 40% of global energy related carbon emissions and 50% of all extracted materials. Additionally, global building stock is expected to double by 2060 as a result of a growing population and urbanization (WGBC, 2019). This means that engineers have a critical role reducing the amount of resources consumed and pollution produced, as well as taking into consideration other global inhabitants' needs and the needs and demands of future generations.

It also means that universities training engineers are well placed to introduce concepts of sustainability at the undergraduate and postgraduate level through directed teaching and research activities. This paper describes the activities of the Institute of Smart Technology in the field of tertiary education and research regarding sustainability.

2 BACKGROUND

The University of Pécs (UP) is the oldest university in Hungary and was originally founded in 1367. It is made up of 10 faculties including economics, medicine, law, and art, as well as the Faculty of Engineering and Information Technology (FEIT). More than 20,000 students attend the university and approximately 4,500 are international students. The FEIT offers several undergraduate and postgraduate programs in architecture, computer science, design, and engineering in both Hungarian and English. There are approximately 3,000 students at the faculty

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of which approximately 700 are international students.

Both the University of Pécs and the Faculty of Engineering and Information Technology, are dedicated to incorporating sustainability at both the institution level and in study and research programmes. In 2022, the University of Pécs ranked 21st from over 1000 participating universities according to the UI World University Ranking Green Metric (https://greenmetric.ui.ac.id/rankings/overall-rankings-2022). This ranking considers the infrastructure, transportation, waste, water usage as well as focus on education and research in the field of sustainability.

The University of Pécs has a 'Green University' (https://zoldegyetem.pte.hu/en) programme where it has set a series of goals in the fields of sustainability, waste management, energy and climate change, and transportation, that it would like to reach by 2030 and 2050. One of the more popular initiatives already implemented at the university level was the installation of free water dispensers throughout all the faculties providing filtered, carbonated or still, hot or cold water to reduce single use water bottles.

At the faculty level, recently there has been an increase in the collaboration with other universities in Europe and in the US in the field of sustainability in research and teaching.

2.1 Sustainability in Education and Research

Over the last few decades sustainability has become more and more important in the world at large and also in education. Many aspects of sustainability can be taught and adopted at the university level especially with engineering students who can play a relatively large role in the use of resources and pollution emitted in the construction industry. With new communication technology becoming mainstream there are more and more options to collaborate with other universities on real world challenges where students have the motivation to become globally responsible engineers.

2.2 International Collaboration in Sustainability Education

The arrival of the corona virus pandemic and the subsequent move to online teaching, ironically, provided more opportunities for collaboration between UP FEIT, MSU Denver (Metropolitan State University Denver) and Brunel University in London. Two different collaborative courses were taught over four semesters with lecturers from Pécs, Denver and Brunel sharing the teaching in their field of expertise.

2.2.1 International Engineering Project

One of these courses, the International Engineering Project, was based on the Engineering Design Challenge organized by Engineers without Borders UK (https://www.ewb-uk.org/), where students worked in groups to solve design challenges for two low-income communities in Peru, and the following year, Aboriginal and Torres Strait Islander communities in Cape York, Australia. Undergraduate students from a variety of majors (civil engineering, architecture, IT, electrical engineering, mechanical engineering, environmental engineering, sustainable systems engineering) were divided into mixed groups with members from MSU Denver, University of Brunel and UP. In addition to attending the lectures held weekly, students completed their own research into the challenges and viable solutions out of class time. Considering that the groups consisted of students from three different time zones, different cultural and academic backgrounds, the end results (a video and technical report), were consistently high quality. The Engineering Design Challenge is also a competition and some of our students built models of their designs and got selected by the British panel of judges for further progression in the competition. The feedback from the students was that the course was a valuable course, not just for the technical design component, but also because they got first-hand experience of doing research and working in groups towards a common goal. These soft skills of working in culturally diverse groups from a variety of academic backgrounds are very much in demand by employers in our globalised world. Sustainability also played a major role in the students' work and their designs were expected to take into consideration the local context as well as the sustainable development goals.

2.2.2 Sustainability in Structures

Another course which also ran for two semesters was the course Sustainability in Structures, which was a collaboration between MSU Denver and UP, and was initially open to MSc structural engineering students, but later expanded to include MSc architectural design students and sustainable systems engineers. As the name of the subject suggests it focused on how students could incorporate different aspects of sustainability into their engineering studies and future work. In addition to the weekly lectures where both universities gave lectures or organized guest lecturers from the professional community, students were expected to carry out their own academic research to answer specific questions related to aspects of sustainability in the engineering field. Another component of the course was participation in an intensive design project where students had to come up with a design for a fire lookout tower one year and the design of a short span pedestrian bridge the following year. The intensive project took place online during the spring break and involved groups made up of students and lecturers from UP, MSU Denver and Dortmund University of Applied Sciences and Arts in Germany.

This close collaboration showed that it was possible for the faculties to work together and was a large part of the motivation for a longer multidisciplinary program dealing with sustainability in engineering. In 2023, our faculty submitted a proposed postgraduate programme in Sustainability for the Built Environment for accreditation to the Hungarian Accreditation Committee. This programme started out as a collaboration with MSU Denver and UP expects to run this joint programme with MSU Denver in the future.

In 2023, the course Sustainability in Structures no longer runs in collaboration with MSU Denver, due to the end of online classes, so it has been reorganised to provide students with the skills and opportunity to do research in the field of sustainability and structural engineering. This course has become a source of recruitment for students to join one of the faculty's research groups where they can make use of the laboratories and equipment at the university to carry out research and compile their results for publication in a journal. The course also teaches students about the process of carrying out research and the format of academic studies and articles.

2.2.3 Promoting SDGs in HEI

Our faculty is also taking part in an ERASMUS funded project in collaboration with the University of Burgos (Spain), DELFT University (Netherlands) and Trinity College Dublin (Ireland). JOIN-RISe – 'Joint development of innovative blended learning in STEM curricula based on SDGs for a resilient, inclusive and sustainable education' aims to provide support for teachers and promote teaching of the Sustainable Development Goals (SDGs) at higher education institutions.

As part of this project, participants at our institution conducted research about incorporating sustainable development goals into STEM teaching programmes. Based on the results of this survey we identified that there is a real demand for sustainability in engineering and, although many teachers already incorporate many aspects of environmental thinking into their teaching, there remain many challenges that need to be overcome.

One problem is the compulsory syllabus which leaves very little time for the introduction of new material which isn't directly related to the existing course material. Another issue is the perceived lack of materials available for teachers and a lack of time and resources to create new material.

To overcome some of these issues there are numerous recommendations and guidelines that aim to assist with our faculty and other HEI to transition to a more sustainably inclusive curriculum. It is important to note that some of these guidelines may not be suitable for every institution but using a combination depending on the priorities and individual nature of the teaching programme is likely to be the best approach.

Universities need to encourage teachers to either develop new courses which directly focus on sustainability or incorporate different aspects of sustainability into existing courses. There are a large number of materials which are free or open source online such as SDG Academy which offer a curated collection of short and longer courses that can be adapted for use at a university. An up-to-date database of suitable activities which are categorised according to STEM subject and SDG needs to be compiled where teachers can get immediate access to teaching materials which they can either use off the shelf or adapt to their situation. Ideally each institution would have their own local platform where teachers can signify if they have used a resource to avoid constant repetition by another teacher for the same class of students.

The survey showed that a lack of preparation time is a primary reason for teachers not developing their own teaching resources. This is especially true if it is an area outside of the teacher's area of expertise. Funding and time is needed to allow teachers to develop their own course material that focuses on raising awareness and educating students about SDGs. It is important that teachers realise that they are changing the beliefs and values of students rather than just transferring knowledge. The Faculty of Engineering and Information Technology has a large number of international students who attend as part of the Hungarian Stipendium Scholarship, and many of these students are from low- or medium-income countries, and it is important that students can see how they can transfer their knowledge to their own communities through their work upon graduating.

Tandon and Chakrabarty (2018) note that engaged teaching means building partnerships with local actors, and that teaching all subjects become more engaged when dealing with the real world and society and not just restricted to the classroom. It with this mentality that the faculty sets specific tasks with students to solve a real-life challenge, making it more engaging for students, where they can see how real communities might benefit from their actions. A good example of this is the Engineers without Borders Design Challenge (https://www.ewb-uk.org/upskill/design-challenges/) which deals with real-world problems in disadvantaged communities abroad. The concept behind the Design Challenge can also be adapted to solve problems in local communities where students conduct fieldwork and research allowing them to better see the local context and how people's lives can be improved through sensible design. By having multidisciplinary groups, especially from a variety of cultures, it allows students to explore more viewpoints, and learn to negotiate when coming up with a design and gives student experience that they will have to face when they graduate and will interact with other professionals outside their field of specialisation.

Students at the faculty were invited by the Engineers without Borders UK to form a student chapter of the organisation. This is a student run organisation with the aim of "advocating for globally responsible practice through extracurricular activities" (https://www.ewb-uk.org/student-chapters/). As part of this initiative, there have been multiple activities which have been organised, including engineering students visiting secondary schools to talk about the importance of sustainability in engineering, running workshops, taking part in competitions, organising guest speakers, networking activities, etc. In 2023, the Pécs chapter applied for funding to expand the number of outreach events that will be held to reach a larger number of secondary and university students in the local community.

2.2.4 Collaboration with Industrial Partners

According to Tandon, structured and regular interactions with local actors may also generate research questions that have relevance for sustainable development goals (Tandon, 2017). Our university has numerous relationships with business partners in the construction and engineering industry and these collaborations provides a source of recruitment for companies and widens the scope of potential research topics to include real world projects that these companies face. Industrial partners can often provide funding, materials, and equipment to support research and the university can provide the specialised research labs and expertise to conduct research. These collaborations are a way to bridge the gap between academia and industry, leading to more effective transfer of knowledge and technology and by involving both academia and industry there is a greater possibility of coming up with more innovative and cost-effective solutions. If a university can demonstrate that they are committed to addressing real challenges, it can also enhance the reputation of the university.

2.3 Involving Students in Research

Through education and collaboration with industrial partners in the field of civil engineering, our students are involved in several research projects focusing on issues related to the sustainability of the built environment. An overview of these is given in the following sections.

2.3.1 Innovative Recycling of Concrete Waste

Concrete is one of the most widely used materials in the world and it is estimated that it will continue to be used in increasing quantities in the future. It is perhaps the most important material for our built environment, but its production and use still produces huge CO_2 emissions with the technologies currently used (Andrew, 2018). Besides cement, an essential component of concrete structures is aggregate, which has become more and more difficult to source without significant energy consumption and environmental damage. It is a non-renewable raw material, and its reserves are depleting. The expected demand for more and more demolition of our existing concrete and reinforced concrete structures due to deterioration and obsolescence will create a huge amount of waste in the future. The storage of concrete waste may soon become a major environmental problem, as the trends indicate that the amount of concrete waste from the construction industry going to landfill will increase year by year (Katz, 2004). Solving the problem of recycling concrete waste from construction is therefore a priority for society.

While the use of recycled concrete has recently increased significantly in several countries across Europe, in Hungary this process seems to be much slower. Perhaps the most important obstacle to the uptake of the technology in Hungary, apart from the lack of sufficient domestic experience and the strictness of current regulations, is the fact that there is generally a lack of customer demand. It is, however, a welcome trend that the selective collection and preparation of construction and demolition waste for recycling is becoming more and more common in the domestic construction industry.

A good example of this is the management of waste from the demolition of the 25-storey "High-rise" building in Pécs in 2016 (Figure 1), which alone generated more than 22,000 tonnes of debris. Despite the fact that demolished concrete debris is considered a good quality raw material and is relatively homogeneous, its recycling as a raw material for concrete has not yet been fully achieved, and a significant part is still stored awaiting further use (Figure 2).

In the domestic context, too, the majority of collected concrete waste is used for backfilling and road construction, even though a large part could be used as a concrete aggregate, even if it meets higher quality requirements.

Figure 1: Demolition of High-Rise Building in Pécs, 2016.

Despite the current difficulties, it is clear that concrete recycling is a key element for the future sustainability of our built environment. Based on the above mentioned background, the UP FEIT, together with industrial partners, has launched an extensive research programme on the recyclability of concrete. One of the main objectives of the research is to provide a broad knowledge of concrete technology and laboratory background to help identify and overcome barriers to concrete recycling, based on the knowledge of the domestic situation.

Figure 2: Processing and landfilling of the concrete rubble of the Pécs High-rise building.

In the framework of the programme, several tests have been carried out by university students on the usability of different recycled and reclaimed concrete aggregates, including an analysis of the concrete aggregate from the demolition of the "High-rise" building in Pécs, mentioned earlier. The tests showed that, contrary to popular belief, even higher compressive strength can be achieved using recycled aggregates than using only natural aggregates, with essentially the same concrete composition. Our studies have shown that the main problem is not to achieve the required compressive strength, but to optimise the mix design in order to obtain a mix with adequate fresh concrete properties (consistency, durability, workability) (Kashkash et. al, 2021).

The widespread industrial application of recycled concrete requires not only the optimisation of the material properties of the end products. It could be equally important to analyse the health risks of recycling, to minimise or even reach negative CO_2 emissions over the life cycle of the products produced, and explore other possibilities for using the raw materials including innovative energy storage solutions for other industrial sectors. For a wide range of applications in the construction industry, it is generally necessary to increase the performance of concrete products produced and the safety of the production process. This not only concerns strength properties, but also other characteristics such as durability and workability. In order to optimise the process, it is necessary to improve the current design process and the testing methodology prior to concrete design. Based on the measurable properties of a given concrete waste raw material (which may even be in its pre-consumer state), the composition of the recycled concrete mix can be optimised for specific applications (Czoboly et. al, 2021).

The results of the research have been effectively integrated into the curriculum, in the development of which our students have been actively involved. Several theses, conference presentations and student competition papers have been produced based on these research results.

2.3.2 Reuse of tyre steel wires in concrete

It is estimated that more than one billion used tyres are generated worldwide every year. The reuse of the steel wires in tyres for industrial purposes is difficult. However several researchers have proposed an alternative solution whereby steel fibres extracted from tyres are used in concrete technology (Wang et. al, 2000).

With the participation of our university students, a research project was launched on the environmentally and economically sustainable recycling of steel wires in used tyres. In this application, the steel wires extracted from tyres (Figure 3) are mixed with concrete to modify its mechanical properties.

One of the main problems when mixing steel fibres extracted from tyres into fresh concrete is that the fibres tend to clump together, making it difficult to mix and distribute the fibres evenly. These steel fibres have irregular geometric properties and often contain rubber particles on their surface. However, with proper preparation, these impurities can be removed. The research showed that fibres extracted from tyres improve the overall properties of hardened concrete, apart from difficulties in mixing (Senesavath et. al, 2022). As this mixture is produced by recycling waste material, it is considered an environmentally friendly and economical solution.

Figure 3: Steel wires extracted from used tyres.

2.3.3 Smart Monitoring

The sustainability of our built environment can be promoted not only by creating new buildings with the right criteria, but also by extending the life of existing buildings. In many cases, the maintenance and demolition costs of existing structures are significantly higher than the costs of their construction, but in engineering design practice, whole-life cycle costs and environmental impacts are rarely taken into account. However, the focus should always be on whole-life optimisation and improving life-cycle performance rather than on minimising initial (or short-term) costs in the implementation and operation of a building.

Structural reliability and resilience are very important elements of life-cycle performance. This refers in particular to the robustness and adaptability of structures to changing conditions, while maintaining their functionality and safety, even after various extreme events (e.g. natural disasters,war acts, etc.). The tools for designing structures for increased resilience include, among others, the choice of materials, structural connections, structural systems with adequate durability and ductility, but the provision of structures with appropriate diagnostic and monitoring systems to allow timely intervention in case of adverse deterioration of the structural condition is currently an unexploited area (Orbán, 1997). This can significantly increase the safety of the built environment, reduce the costs of reconstruction in the event of natural disasters, increase the life expectancy of structures and, in the long term, reduce the use of additional building materials and the problem of waste disposal due to demolition.

Advanced building monitoring systems are able to collect data on the condition of buildings and their environment in an integrated way. Experience over the past decades has shown that, in addition to the parameters that determine thermal performance and occupant comfort (e.g. noise, temperature, humidity, CO_2 and volatile organic compounds), it is also useful to monitor the structural condition of buildings. Procedures based on the combined use of several, mainly non-destructive, structural diagnostic and monitoring methods can be effectively applied in the investigations of buildings and structures (Orbán, 2006).

Structural Health Monitoring (SHM) systems use sensors and data collection devices to collect information on the state characteristics of the building's load bearing structures and the environmental factors relevant to their functioning, and then analyse the measured data to assess the condition of the structure. The primary objective of continuous data collection and assessment is to provide early warning of any deterioration that may threaten the safety of the structures or their environment. The collection and evaluation of data can also provide vital information for subsequent decisions regarding renovation, maintenance or strengthening.

Smart monitoring systems usually automatically provide real-time data on the condition of structures over long periods of time and combine data collection, transmission, storage and analysis in an integrated system. In recent decades, this type of monitoring technology has become a popular research topic in the field of asset management and, like computing, has developed very rapidly. Today, there is a very wide range of monitoring measuring devices and equipment operating on different principles.

Figure 4: Instrumental crack monitoring system on a listed building.

Measurements can be aimed at the determination of displacement, vibration, crack width or crack propagation, corrosion, etc. characteristics at certain intervals or at continuous measurements. An example of instrumented crack monitoring on a listed building is shown in Figure 4.

Satellite radar interferometry (InSAR = Interferometric Synthetic Aperture Radar) is a technology that is primarily used to detect surface deformations. It is processed to derive an interferogram from the relative phase difference between two or more images, and then to calculate the magnitude and velocity of the surface deformation between the surface of the object under investigation and the satellite (Line of Sight - LOS). In the case of multiple images, time series analysis of these images also reveals the deformation history of the surface feature, allowing the measurement and monitoring of periodic or long-term (centimetre or even millimetre scale) deformations (Figure 5).

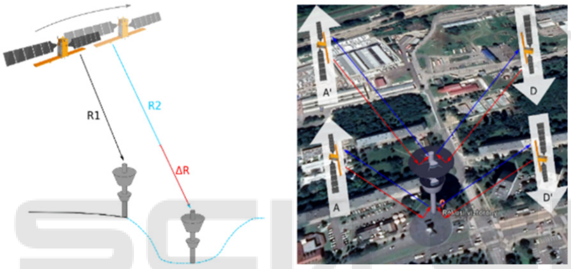

Figure 5: Stability monitoring of water tower using InSAR technique (Orbán et. al, 2021).

The success of this technology in structural monitoring has been demonstrated in a number of scientific publications (e.g. Milillo et. at, 2019).

The FEIT Structural Diagnostics and Analysis Research Group carries out research to harmonise satellite radar interferometry and diagnostic and monitoring techniques used in engineering practice. The aim of the research is the development of a satellite radar-based displacement monitoring system, which is used in combination with conventional monitoring techniques (e.g. geodetic surveys, 3D laser scanning, drone photogrammetry, monitoring with crack and displacement sensors, ground-based interferometric radar surveys, vibration measurements, etc.), and is complemented by multidimensional data fusion and numerical simulation mathematical techniques (Ronczyk et. al, 2022).

2.3.4 3D Concrete Printing

The industrial-scale application of additive manufacturing technology for construction products is one of the most important directions of development in the construction industry today. In the near future, the construction industry is expected to experience a technological revolution, one of the main focuses of which is the application of 3D printing in construction. Increased accuracy and optimisation of the entire value chain through digitalised industrial manufacturing and 3D printing may significantly reduce CO_2 emissions, and it is expected that materials incorporated through printing will be efficiently recycled at the end of the structure's useful life. The widespread use of digital and automated technologies in construction manufacturing methods is currently at an early stage compared to other industries, so there is huge potential for development activities in this area.

Figure 6: 3D Concrete Printing laboratory.

Figure 7: 3D printed concrete wall element.

Our research group is developing a 3D printing technology chain and printable concrete materials with university students, in collaboration with national and international industrial partners (Figure 6 and 7). The research work on materials aims to develop concrete mixes based on a locally available river sand aggregates, domestically produced high-strength cement binders, domestically sourced additives and chemical admixtures.

An important consideration in the laboratory tests to determine the composition of concrete, is that the material of the printable concrete mix must have sufficient consistency to allow the concrete layer to be printable, but also sufficient strength, i.e. stability without significant deformation, to withstand the stresses caused by subsequent layers (Figure 7).

In addition to concrete mix developments, the research investigates the specific mechanical properties of hardened concretes produced by 3D printing technologies belonging to a given technology group, as well as the potential for combining them with 3D metal printing technologies. The research will also investigate the effects of additional characteristics and parameters (e.g. anisotropy, anomalies due to printing layer boundaries and other geometrical factors, quality irregularities, technology induced porosity, micro-fibre reinforcement, etc.) on structural behaviour and load bearing capacity, for which we do not yet have adequate data to integrate into the design process.

3 CONCLUSIONS

As documented in the paper the importance of introducing concepts of sustainability to engineering students at the undergraduate and graduate level is significant. Collaboration between different universities and trying to solve real life engineering problems can be a key motivator for students to use their engineering skills as well as soft skills such as working as part of a team from a variety of different cultural and academic backgrounds. Collaboration with industrial partnerships can offer many mutual benefits to help come up with innovative market solutions. Active participation of students in research groups can assist with coming up with viable sustainable solutions for numerous challenges.

There is an increasing demand for universities to incorporate concepts of sustainability into the curriculum and it is up to HEI to cater for this demand.

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