Engineering design for the cultural world heritage: reflections from the implementation of a challenge-based learning approach.

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ABSTRACT

Ingenjörsmässighet today is a matter of being able to engineer complex and multifaceted systems, to empathize with users, clients, and stakeholders to know more (and know better) about the problems to be solved, and to judge the ‘goodness’ of proposed solutions across social, political, technological, cultural and environmental values. Challenge-Based Learning (CBL) has been promoted in recent years as a means for students to align the acquisition of disciplinary knowledge with the development of transversal competencies while working on authentic and sociotechnical societal problems. This paper aims to contribute to the CBL discussion by presenting the lessons learned related to conducting engineering design projects with a focus on issues and themes related to innovation in the cultural heritage domain. The paper describes how engineering design projects at the undergraduate level have been set up and conducted to cope with different innovation challenges related to the World Heritage Site of the city of Karlskrona in Sweden. It elaborates on how design projects with a cultural heritage theme can leverage how students learn about ‘softer’ and more intangible dimensions of ‘value’ (for products, systems and services).

KEYWORDS

Challenge-Based Learning, Design Thinking, value innovation, Cultural World Heritage.

INTRODUCTION

Rapid changes in technology, society, environment, mobility, and workplace are transforming the understanding of engineering and how ingenjörsmässighet (Uppsala University 2005) shall be defined. Engineering systems are increasingly characterized by social, political, technological, cultural and environmental values (Huntzinger et al., 2007). Acting and thinking like an engineer is no longer a matter of optimizing solutions for functionality or performance (Bourn and Neal 2008). Instead, engineers must be able to empathize with users, clients, and stakeholders to know better about the problems to be solved, to generate original solutions, and to iteratively select the winning design concept across a range of tangible and intangible value criteria. The academic debate...
often focuses on how to align the acquisition of disciplinary knowledge with the development of transversal competencies, while working on authentic problems able to develop such skills. How to design learning situations in which the students are exposed to heterogeneous values, preferences, feedback, and arguments?

Designing experiential learning activities with a Cultural World Heritage (CWH) theme is explored in this paper as an answer to this question. In the current context of changing demographics and climate, diminishing resources, and growing threats, the development and preservation of CWH must balance conservation objectives with a broad range of economic, social and environmental values (UNESCO 2015). Promoting engineering design projects rooted in the CWH challenges is thought to raise the students’ ability to work with complex and interdisciplinary problems and values, boosting their ability to engage with external stakeholders (local communities, citizens, visitors and more). This presents the ‘whys’, ‘whats’ and ‘hows’ concerning the opportunity of collaborating with CWH in engineering education at the undergraduate level. The objective is to review the existing literature on the use of CWH as testbeds in engineering education and to illustrate how course projects have been set up and implemented in collaboration with the World Heritage Site of Karlskrona in Sweden. The paper discusses how the students have worked to translate the initial challenges into development problems using a value-driven design approach, and how they have worked in co-production mode with the CWH site management to propose demonstrators, test prototypes and follow up on the outcomes of their work. The paper presents the lessons learned from the collaboration and reflects on the value of these projects from a Challenge-Based Learning perspective.

**WHY COLLABORATING WITH CWH IN ENGINEERING DESIGN EDUCATION?**

Cultural Heritages express the ways of living developed by a community and passed on from generation to generation, including customs, practices, places, objects, artistic expressions, and values. CWH take this notion further, as they represent a global heritage that belongs to everyone. CWH are often seen as ‘living’ entities (Wijesuriya 2018), being characterised by a constant process of change, being the theatre of interaction among people and their complex, historically multi-layered, culturally diverse living environment. Various interests, needs, and values affect this process of change, raising plentiful challenges and opportunities for innovation and development. The successful management of a ‘living’ CWH depends on the ability to design highly innovative solutions that can cope with a variety of public and private, global and local stakeholders, all affected by this change process.

*Why collaborating? An academic perspective*

Hu, Li and Cao (2022) recently discussed the need for engineering design interventions to innovate and protect cultural heritage. These are acknowledged to play a starring role in enabling contemporary consumers to obtain a complete physical and mental experience of a heritage, and to establish its correct and accurate cognition. A living CWH needs to be innovated, following the development of technology and culture, to be better integrated into contemporary society and to fulfil its role of continuously promoting its outstanding universal value. Product design, service design, and interaction design are described as the three pillars needed to balance conservation and development in cultural heritage sites, to identify solution strategies and actions that, for instance, can
balance the conservation objectives with the need to alleviate poverty and create more jobs in a city or region.

The multifaceted, cross-disciplinary problem statements emerging from CWH provide a fertile ground for applying Challenge Based Learning (CBL). This is an experience where learning occurs “through the identification, analysis and design of a solution to a sociotechnical problem” (Malmqvist et al., 2015). Engaging students in ‘real-life challenges’ is a core characteristic of CBL. These shall be ‘authentic’, rooted in themes of global importance, derived from professionals’ activities, and closely related to students’ interests and development. While traditional (and ‘problem-based’) learning is based on university-developed challenges, CBL is actively supported by stakeholders, often involving them in assessing student work. CBL is characterised by a strong need for action (Kalinga and Tenhunen 2018), making students explore topics from diverse fields allowing them to discover links between far-away disciplines and domains.

**Why collaborating? A CWH management perspective**

Engineering design projects fulfil an important function in relation to the 5 strategic objectives of the UNESCO World Heritage Convention (UNESCO 2015), which are: Credibility, Conservation, Capacity Building, Communication and Communities. The latter two are critical to raise public awareness, involvement and support for the CWH. Engineering design projects are an opportunity to exploit technology not only to ‘preserve’, but also to ‘communicate’ the values of a site to citizens and visitors, sharing the rationale why a CWH is worth preserving. Inquiry, dialogue, creative problem solving, and storytelling are then the major drivers for the collaboration.

CWH are also pointed out as role models and leading examples for fulfilling several goals of the 2030 Agenda for Sustainable Development (https://sdgs.un.org/goals). Engineering design collaborations at the undergraduate level can be connected to Sustainable Tourism targets (Goal #8), to Goal #4 (which is related to inclusive and equitable quality education), and to Goal #11, which aims at making cities and human settlements safer, resilient and sustainable. The ‘capacity building’ aspects of Goal #17 are also lifted by the collaboration. The latter creates a contact point with the ‘young adults’ target group, which is difficult to reach using traditional communication channels and methods. The engineering design projects are therefore seen as an opportunity to make the group more aware of the cultural value of an heritage site, more engaged with the local community and more able to contribute to the development of their environment.

**WHAT ARE THE MAJOR COLLABORATION MECHANISMS TODAY? A REVIEW**

The rapid pace by which new technologies and business models are developed today opens up the design space concerning the preservation and development of tangible and intangible heritages (Alivizatou-Barakou et al. 2017). The application of engineering design methods in the realm of CWH has been discussed by several contributions (e.g., Fiorineschi et al. 2020, Bici et al. 2022), yet often with a research focus rather than from an educational viewpoint. With less frequency, the literature reveals several examples related to the use of CWH as testbeds in engineering design education.

Examples in education include Suominen, Halvari and Jussila (2019), who describe the use of the inhabited World Heritage city of Rauma as the primary setting for a hurban-educational hackathon. The activity moved from background information provided by the
Chairman of the Rauma Entrepreneur Association, who shared a perspective on the urban challenges of a World Heritage city with the modern needs of inhabitants and visitors, such as the change of generations, the revolution in retail, digitalization and e-commerce, and a changing environment. Vázquez-Villegas et al. (2022) show how to design a culturally relevant academic experience for university students to involve them in preserving biodiversity while developing research and problem-solving skills. Deng et al. (2022) elaborate on the concept of STEM education (including the four areas of Science, Technology, Engineering and Mathematics) (Martín-Páez et al. 2019) to propose a C-STEAM, which leverages culture, arts and humanities and is inspired by the values of Intangible Cultural Heritage. C-STEAM focuses on students’ learning and on the transmission of intangible heritage, allowing students to innovate while bringing forward traditional cultural values through the use of advanced technologies.

**HOW TO COLLABORATE? THE CASE OF THE VALUE INNOVATION COURSE**

The 7.5 ECTS Master Programme course named ‘Value Innovation’ - which is part of the ‘Innovative and Sustainable Product Development’ specialisation of the Mechanical Engineering programme at BTH – is currently working as the main hub for collaborating with the municipality of Karlskrona on CWH-related themes. The reason for prioritizing this mechanism - compared to an MSc thesis or larger capstone projects - is to accelerate the learning curve for establishing a higher-order collaboration between the academic environment and the public institutions. Short, small-scale projects are low-hanging fruits to bridge the gap between innovation experts in academia and CWH practitioners.

The current focus of the collaboration is showing ‘what’ is possible – to raise interest among a large and different group of stakeholders – rather than to detail ‘how’ results shall be implemented. The interest lies primarily in exploring different solutions strategies and in realising quick-and-dirty ‘prEtotypes’, which are used to facilitate the discussion among different individuals and roles. Hence, such small-scale student projects are discussed as the optimal trade-off between quality (of the results), lead time (for producing the results) and effort (for managing different projects across different teams).

**Course design and toolbox**

The course builds on the Design Thinking (DT) methodology framework (Leavy, 2010) to raise students’ understanding of how to develop innovative products and services, focusing on value creation. It spans 8 weeks and features design and innovation lectures, including a mix of short theory reviews and active work in different group constellations. These are complemented by workshops and class exercises that give participants a first-hand experience of the most relevant tools in the DT toolbox. In line with the CDIO framework, the course is designed with an overarching project work that kicks off just after the course introduction and stretches along the entire study period. Each project is conducted by small teams (4 to 6 participants), mixing students from Industrial Economy (year 5), Mechanical Engineering (year 4) and international students (years 4 and 5). Experiences and lessons learned from the project work are shared during presentation events in the classroom. Peer evaluation and group coaching (feed-forward) stimulate critical reflection regarding the process and the results. Results are gathered in a written report, constituting the grading basis. Individual self-reflections encourage students to learn about methods and tools for value innovation.
The course projects are centered on the development of ‘solutions’ to a given design problem, focusing on the technical, business, social and cultural aspects that make them value-adding. Here, the students choose different DT and innovation engineering tools (from the literature) to create their own customized version of the ‘value innovation’ process (see Figure 1), which is usually applied and iterated 2-3 times.

The first step is to frame the challenge and describe the problem with a higher granularity (Value Discovery). In the second step (Value Mapping), the teams gather needs and requirements from the selected target group, starting with early adopters and extending the search to more groups. Field data are complemented by the outcomes of trendwatching/ techwatching activities, and by benchmarking competitors’ products. The team creates suitable design concepts - typically by being inspired by solutions proposed in different domains – and will down-select them through the use of a relevant concept selection approach (Value Creation and Assessment). The team is then expected to develop and verify prototypes in co-production mode with their external liason (Value Simulation). Preliminary prototypes are presented halfway through the course and are mainly used to gather more needs, generate better ideas and refine the solution before the final presentation. The final project delivery is in the form of a working prototype (physical or virtual) accompanied by a Total Cost of Ownership or Net Present Value analysis that considers aspects such as manufacturing, installation, operation, maintenance and decommissioning of the solution.
Project example: Code-of-conduct reinforcement

In the last five years, students in the course have been offered the opportunity to select (among other proposals) CWH-related projects sponsored by the municipality of Karlskrona. Notable examples include the project series “The Invisible World Heritage Site”, whose aim was to design innovative solutions to improve the visibility of most secreted areas of the site, which are used today for military purposes and not accessible. Other projects looked at the ‘productification’ of CWH’s outstanding value, leveraging Karlskrona as a tourist destination through innovative products and services.

The 2022 edition of the course featured a total of 16 students (divided into three groups, Project A, B and C), who were tasked with the development of solutions to reinforce a Code of Conduct for both the Cultural World Heritage and Biosphere reserve. The questions in the initial brief were open-ended, and formulated as the following: What are the behaviours to encourage among visitors, and what are the ones to discourage? How can we together communicate to people/tourists how to behave? How should we convey our message, and in what format (i.e., product, service, software or ‘solution’)?

The work was initially focused on defining a map of stakeholders to be involved in the different need-finding activities for the challenge. The students were supported by the site management in establishing the initial contacts with workers in public offices, members of the municipal tourism board, citizens and communicators. Data from interviews and focus groups were triangulated with the analysis of internal documents, including statistics related to the flow of tourists in the site, the results of sustainability analysis and examples of Code-of-Conduct being benchmarked by the site manager.

Trend- and tech-watching activities filled the knowledge gap concerning the technological possibilities, informing the subsequent concept-generation activities. The latter engaged different individuals and roles working with the CWH, who also took part to concept selection and prototyping activities. The winning ideas were scaled up and realised physically or digitally, to be later presented to teachers, site stakeholders and other students in an open forum (see Figure 2). The work was characterised by several fast-paced iterations, which have matured the understanding of the original challenge and turned it into a more manageable, practical design problem.

Project A brought to the development of a Smart Bin solution that exploits image recognition technologies to award users virtual points when recycling waste. The bins are located using geotagging, and different points are rewarded depending on the type of recycled waste. These can be further spent in shops, cafés but also for cultural activities linked to the CWH. The working prototype includes a camera, lighting, and ad-hoc software code in MATLAB to recognise different types of waste and sort them in different bins. An app prototype further demonstrated how users collect and spend points.

Project B identified the ‘tourists with children’ persona as the primary target group for the solution, exploiting storytelling to motivate people to behave sustainably and recycle their waste when visiting the CWH. The final solution features a waste bin that, after being activated by throwing trash into it, narrates the story of Rosenbom (a popular character in Karlskrona) while displaying it through images on a rotating disk.

Project C exploited gamification to stimulate citizens and tourists to behave responsibly. QR codes strategically positioned around the town, and in the archipelago, invite
individuals to take a quiz, challenging friends and family members to answer questions related to Karlskrona, its cultural heritage and its natural environment. This solution also has pedagogical content, being linked to a responsible travel pledge, which helps educate tourists and encourage them to behave kindly to the places they’re visiting.

Figure 2: Final prototypes of Project A (left), Project B (center) and Project C (right).

DISCUSSION: ANALYSING CWH PROJECTS THROUGH THE LENSES OF CBL

The analysis of the final student reports, their self-reflections, and the data gathered after the course via interviews and focus groups have shown the efficacy of CWH projects as a testbed for CBL, while outlining some critical areas of improvement.

Both the analysis of the project reports and the feedback from the project liaison show that the students have succeeded in moving from abstract ‘grand challenges’ to more actionable and concrete design projects. The collaboration has been successful in forcing the students to reflect on how to cascade down the initial open-ended project brief to concrete statements and tangible proposals, allowing various solution paths. The projects have shown to foster dialogue with a varied and cross-functional team of stakeholders, from radically different domains. This is not commonly seen in more traditional mechanical engineering projects, which have far less ramifications in the artistic and humanistic domain.

CWH projects have stressed the importance for students to develop new praxis to listen to (and be listened to by) real-world professionals with profoundly different backgrounds. In the long run, this has improved their ability to argue about the ‘value’ of their design, developing a more diverse and multi-faceted narrative than their peers working with more classical design projects. Furthermore, the students have been observed to make significant use of ‘boundary objects’ (Star and Griesemer 1989) – in the form of tangible artefacts, demonstrators and proofs-of-concept - to gain insights and obtain feedback on both the problem statement and the proposed solutions. These ‘objects’ have helped to bridge the communication gap not only between students and stakeholders but also
between different stakeholder groups (which differed significantly in terms of education, background and skills), facilitating a process by which they could build on each other ideas (i.e., during a brainstorming session). While prototyping activities are usually confined to the later stages of the design process, CWH collaborations saw the realisation of such demonstrators very early on in the projects, mainly as a way to empathise, communicate and collaborate with a range of professional roles.

Yet, room for improvement exist concerning the integration of different disciplinary expertise when working hands-on with analysing the needs and developing solutions concepts. The teams have often needed additional external support to be able to include cultural and artistic aspects in the proposed solutions. While valid from a technical viewpoint, the outcomes of the projects have often taken a turn towards prioritizing the optimum in terms of performance vs cost, while neglecting a more humanistic orientation. Hence, an opportunity is seen concerning increasing the ability of the teams to embed cultural values throughout the entire design process, which is today dominated by pragmatic engineering thinking.

CONCLUSIONS

The complexity of the challenge brought forward by CWH stimulates a working mode based on creating an ‘experience’ – through the development of hardware, software and services – rather than of yet-another-product. This has a cascading effect on the student’s motivation and engagement, adding a layer that stimulates creativity and the attitude to search for original solutions.

Students are observed to assume more responsibility to control their learning objectives as CWH projects increase in resolutions, being progressively able to assess their learning needs, secure resources, and plan/conduct targeted learning activities. Students also show an increased ability to contextualise these learnings and define their pathway while defining the problem statement from the original challenge description. The projects have also fostered the development of an entrepreneurial mindset among the students, with some results even being followed up by the teams after the end of the course - outside the academic environment - under the direct supervision of the site manager.

Future work will aim to improve how higher achievement, motivation, risk propensity, autonomy, action orientation, persistence, passion, creativity, and more, are measured systematically in the different projects. The adaptation and application of one of the various survey instruments proposed in the literature is currently being considered for the next course iteration. Of interest is also a comparative study where the development of agency, self-learning and ownership are compared across students participating in CWH projects vs. more classical mechanical engineering ones.

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