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Experiencing Education 5.0 for Civil Engineering

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Abstract

Nowadays, the construction industry's digital transformation processes are challenging civil engineering education. In general, students and society underestimate the civil engineering field as an outdated and archaic knowledge area. Despite the defragmentation and heterogeneity of the sector, advances have been made on the path for Construction 4.0 and 5.0 scenarios. From this perspective, the CONSTRUCT-Gequaltec group of the Faculty of Engineering of the University of Porto have been sponsoring research and technological development using hardware and software targeting construction management solutions. This paper presents the work in progress mainly connected to the curricular units regarding project management in the Construction Section of the Civil Engineering Department. It also targets assumptions of some expected results across the research and innovation priorities from ECTP Innovative Built Environment and United Nations Sustainable Development Goals (SDGs). Two fundamental elements of the teaching practices are presented as the Construction Sites of the Future (Laboratory-Based Education initiative) and Digital products catalogue targeting Digital Twins in Construction (Project Based Learning initiative). The learning outcomes address increasing knowledge of innovative solutions, delivering skills to deploy 5.0 actions, and targeting human-centred and sustainable attitudes and values.

Keywords: Construction 4.0; Worker 4.0; Students 5.0; Civil Engineering 5.0

1. Introduction

The Construction 4.0 concept goes beyond Building Information Modelling (BIM), Artificial intelligence (AI) and Internet of Things (IoT) deployments; it relies on an extreme digital transition of the processes concerning project

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management [1]. Additionally, Construction 5.0 intensives innovative actions targeting people's well-being, plus addressing circularity and sustainable goals [2]. In this spectrum, academic education plays a relevant role in providing competencies and skills for the industry 4.0 and 5.0 revolutions [3]–[9]. However, civil engineering education 4.0 and 5.0 still need to expand research and practice. This work presents practice initiatives connecting new methodologies inclusion in the curricular units, laboratory teaching and projects research in progress at the Civil Engineering Department (CED) of the Faculty of Engineering of the University of Porto (FEUP).

Nowadays, to enrich learning and earn students' attention, gamification methods in Education 5.0 are crucial [5]. Engineering Education 5.0 is beyond IoT, AI and BIM and should target sustainability, humanism, and ethical aspects [10]. However, project management skills are vital to designing and carrying out these innovative projects to achieve the objectives set [1]. Encapsulate that three key concepts of project management, innovation, and sustainability are fundamental to achieving the Education 5.0 for Civil Engineering.

Following this work, we present a background highlighting a gap in Education 5.0 for Civil Engineering. After that, we introduce current and envisaged initiatives for Education 5.0 into the curricular units of the CED-FEUP. Finally, it concludes by reflecting on expected results through systematic teaching and further developments.

2. Background

In order to consolidate the knowledge, a search was conducted in SCOPUS and Web of Science engines using keywords such as "civil engineering", "education", “innovation” and 4.0 and 5.0 related concepts. As presented in Table 1, "civil engineering" and "education" general terms have substantial research knowledge. However, less is observed in the field of civil engineering education over the 4.0 industry revolution concept and much less for the 5.0 one. This highlights the research gap of Education 5.0 initiatives in Civil Engineering.

Table 1. Background search conducted.

Keywords	SCOPUS	Web of Science
"civil engineering" AND education	5572	13311
"civil engineering" AND education AND innovation	293	1672
"construction 4.0"	234	149
"construction 5.0"	6	4
"education 4.0"	557	304
"education 5.0"	39	14
"civil engineering" AND education AND "construction 4.0"	3	8
"civil engineering" AND education AND "4.0"	18	89
"civil engineering" AND education AND "construction 5.0"	0	0
"civil engineering" AND education AND "5.0"	5	50

Tikhonova and Raitskaya (2023) highlighted the vision of the World Economic Forum targeting the top skills for a high technological future, where: i. complex problem solving; ii. critical thinking; iii. creativity; iv. people management; v. coordinating with others; vi. emotional intelligence; vii. judgement and decision making; viii. service orientation; ix. negotiation; x. cognitive flexibility [3]. Increasing immersion in the content and simulating real scenarios are essential teaching tools aimed at developing skills [11]. In a global scenario, engineers ought to perceive themselves as personal change agents and confront humanity's challenges, such as global warming [12]. The civil engineer must master the dimensions of physics, technology, and management so that, through their skills, they can contribute to the development of a better society.

Tech-innovation complementary learning path sought to demonstrate hardware and software solutions in Construction 4.0 [13]. Also, laboratory activities can show the integrative role of Digital Twins [13]. Laboratory-Based Education (LBE) allows students to access cutting-edge research, increasing their development to cooperate better and communicate efficiently, awakening management and leadership skills [14]. Serious games convey learning content and can enhance Information and communication technology (ICT) competencies [5]. Project Based Learning

(PBL) can promote students' real-life practical experience and allow built teams [14], [15]. Mixing learning methodologies may increase the engagement of students with heterogeneous backgrounds.

The Civil Engineering education in Portugal follows the Bologna statute. A Civil Engineer can have a bachelor's degree in 3 years [16]. After, in a second cycle, engineers can be granted a master's degree over a two-year course [16]. Recently, the Integrated Master's degree course (bachelor's plus master's degrees) was discontinued. Before Bologna (2007), the more usual academic path in the universities took 5 years leading to a Bachelors' Degree [16]. Finally, a Doctor of Philosophy (PhD) can be achieved in three or four years [16]. What can be observed is that there has been a reduction in study time. At the same time, new skills, such as those related to ICT, are increasingly needed.

The challenges of Education 4.0 & 5.0, mainly after a post-covid pandemic era, are vast and demand fast and multiple actions [3], [5], [8], [10]. Teachers should promote cognitive activities and stimulate self-learning [6]. At the same time, problems and challenges brought to class should be connected to the market needs. Additionally, promoting open standards and software is highly recommended [13]. Finally, to induce Education 5.0 is not a one-task job. On the contrary, deploying incremental learning activities to find and rebuild solid roots is mandatory.

3. Education 5.0 in Civil Engineering, experiencing new approaches in CED-FEUP

3.1. Programs, Curricular units, and Education actions in the Construction Section

Construction 4.0 and 5.0 concepts are pivotal in the digitalisation of processes in the construction industry. These concepts strongly emphasise human-centred applications and the pursuit of sustainable goals. As we look towards the future, we can expect innovative technologies to become integral to construction processes. Given this trajectory, it is essential to incorporate these topics into the curriculum for civil engineering. By doing so, we can ensure that future engineers are well-equipped with the knowledge and skills needed to navigate and contribute to this rapidly evolving landscape. At FEUP in the CED, we have a backbone bachelor's degree in civil engineering named L.EC, directed nowadays by Professor Miguel Ferraz [17]. The Construction Section, led by Professor Rui Calejo [18], offered three different master's programs, being it:

M.EC - Construction (specialisation) - Director: José Miguel Castro; Duration of 2 Years/4 semesters (120 ECTS), "*The cycle of studies aims to train engineers capable of conceiving, designing and managing Civil Engineering systems, structures and construction works, applying updated and adequate methodologies of analysis, materials, equipment and processes, with respect for Ethics, Environment and the best interests of the Community.*" [19].

MPRINCE - Director: Bárbara Rangel Carvalho and, Assistant Director: Jorge Moreira da Costa; "*The MPRINCE - Master in Integrated Design in Building Construction, is a postgraduate course with a duration of 2 Years/4 semesters (120 ECTS), essentially directed at students already graduated - and, even, professional activity - in the areas of Civil Engineering and Architecture, which aims to recreate, within the framework of a specialized academic training, the most efficient model of multidisciplinary development of building projects, referred as IPD Integrated Project Delivery.*" [20].

MBUILD - Director: Jorge Moreira da Costa and, Assistant Directors: Diego Calvetti / João Pedro Poças Martins [21]; "*Master Degree in Sustainable Design, Construction and Management of the Built Environments - is a EMJM Erasmus Mundus Joint Master delivered and awarded by the University of Porto (UP Porto, Portugal), University of Cantabria (UC Santander, Spain) and Technische Hochschule Mittelhessen (THM Gießen, Germany). MBUILD is a 2-year 120 ECTS programme with full involvement of the partner HEI. MBUILD aims to give an answer to identified difficulties faced by European Construction Industry companies, mainly when working in developing countries, in implementing projects with a high level of sustainable and environmentally conscious solutions.*" [22].

Adding to this, the CONSTRUCT-Gequaltec research group, led by Professor Hipólito de Sousa, researches "*Efficient management – processes, use maintenance & facility management, information systems & BIM. And, Building smart technologies - Innovative and smart materials & systems, Non-structural fire risk assessment, Life cycle and sustainable assessment*" [23]. Finally, at the PhD level the Doctoral Program in Civil Engineering (PRODEC) Directed by Elsa Caetano, account with the specialisation in Construction connected to the Construction Section (180 ECTS credits, 3-years) [24].

More engaged in the activities connected to management curricular units and the Education 5.0 assumptions there are the Professors who were authoring this paper: Diego Calvetti (DC), Pedro Mêda (PMD), Hipólito de Sousa (HS),

Miguel Chichorro Gonçalves (MCG), José Manuel Amorim Faria (JMAF), Jorge Moreira da Costa (JMC). Fig. 1 presents the group intentions regarding Education 5.0 based on three main pillars: Project Management (PM), Tech innovations (TI), and Sustainability (SB), targeting to acquire some relevant competencies across the curricular units highlighted:

Project FEUP - L.EC [17] - DC and others ; It aims to introduce first-come students to a broad view of the civil engineering field. Additionally, topics of ICT as valuable tools for engineers are presented in the laboratory (LBE). Also, a visit to a design office is promoted where the BIM use is highlighted.

Capstone Project - L.EC [17] - DC and others; It aims to realise a project in Civil Engineering in a real practice environment. The project can occur in two ways: Curricular internship in a company, R&D unit or FEUP laboratory (LBE). Or involvement in a project in an academic environment at FEUP (PBL). In this, we target to promote capstone projects connected to PM, TI, and SB for students.

Economics and Management - M.EC [19] - DC and others; "*It aims at the education of future engineers able to implement economic-leading projects and be aware of the whole set of inter-relations among different realities, requirements, people, resources, and knowledge fields*" [19]. Project management concepts, tools and techniques are explored and contextualised by industrial practical cases (PBL), also, sensing technologies are introduced (LBE).

Construction Management M.EC [19] - MCG, JMAF, HS, DC & PMD; Students are sensitised to the importance of management to ensure the effectiveness of results and process analysis, fitting into the legislative and regulatory context. Group activities explore the main tools to overcome project challenges to implement civil works based on real situations (PBL). Also, new techniques based on hardware and software to monitor site progress are explored in the laboratory (LBE).

Management of Construction Projects - MBUILD & MPRINCE [20], [21]- HS, JMAF, JMC, PMD & DC; It intends to provide students with the knowledge and competencies enabling them to understand and manage the development of a construction project, mainly in its inception and design stage. Multiple topics are explored over the application and case analysis of construction digitalisation research projects at the design stage using ICT (PBL).

Management of Construction Works - MBUILD & MPRINCE [20], [21] - JMAF, HS, JMC, DC & PMD; It aims to understand the endogenous and exogenous conditions that affect a site, its safety conditions and risk factors of accidents, strategies for workspace efficiency and prevention of accidents. Laboratory practices deliver awareness of technologies and processes for digital control of works and their integration with BIM (LBE).

New Trends for Construction Development and Research - MBUILD [21] - JMAF; Laboratory practices activities to make the students acquire knowledge in the field of new trends of ICT and digitalisation in the AEC sector, such as 3D printing, LiDAR, sensing technologies, big data, machine learning and digital twins (LBE).

Sustainability in Building Design - MBUILD [21] - JMC & DC; It will try to guide the students through the several primary areas of expertise in developing a sustainable building design proposal. For each expertise, with the involvement of professionals sharing their on-hands experience in live lectures, to provide a set of reflection/analysis/exploration routes that may help the students find technical answers that will enable them to propose sustainable and integrated solutions for the context of a specific project (LBE).

Integrated Project – MPRINCE & MBUILD [20], [21] - JMC, DC and Bárbara Rangel (BR); project-based studios, where Engineers and Architects collaborate under an Integrated Project Development IPD approach to achieve a proposal within a brief inspired by an actual company or institution, exploring IT tools for design, coordination and manufacturing of sustainable and evolutive building solutions.

Quality in Construction - M.EC [19] - JMC & DC; It intends to give the students an overview of the several aspects involved in building design, construction and maintenance, through the prism of the application of analysis and exploration of methodologies for increased efficiency in individual and collective work (LBE).

Construction Economy and Performance - PRODEC [24] - JMC; It aims to understand the diverse issues that influence the performance of construction companies and apply methodologies such as using ICT to evaluate such performance, where laboratory experiments may lead to proof of concepts (LBE). Project use case analyses are used to acquire knowledge in identifying and determining KPIs over these to define short- and long-term management strategies (PBL).

In the project management field, it is expected to achieve the students' competencies, such as leadership and entrepreneurship, doting them to be able to identify project KPIs. Also, students are expected to have new competencies to work on sustainable projects, targeting their profitability with environmental responsibility and

putting the people at the core of business. Finally, managing innovative solutions IT-based, using cutting-edge tools and techniques to solve the construction industry's major problems.

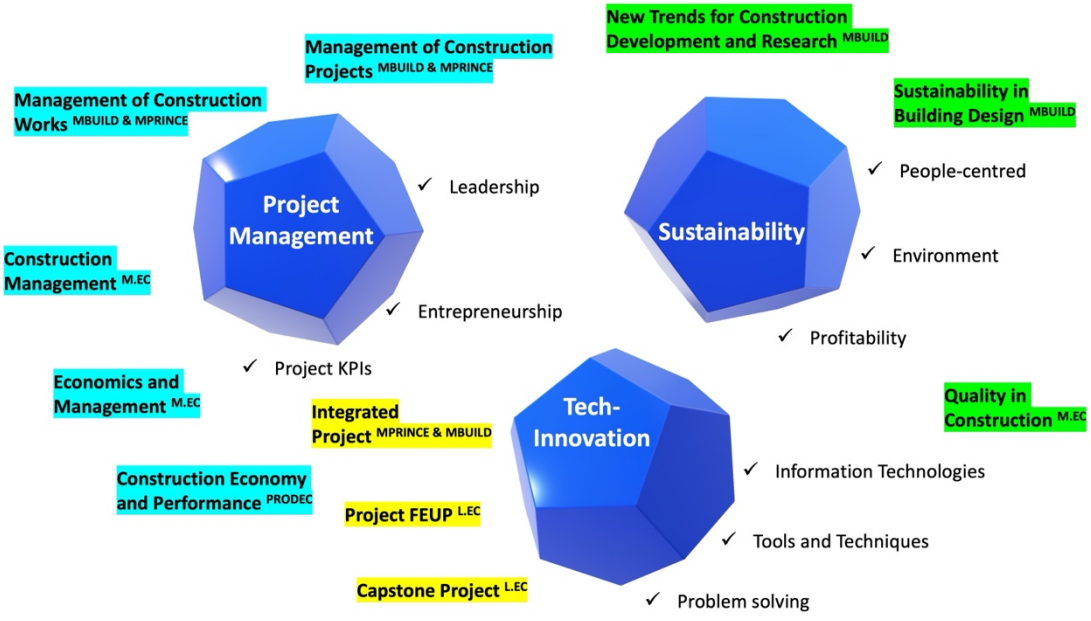

Fig. 1. Education 5.0 for Civil Engineering at CED-FEUP.

In the context of PM and TI, it is necessary to enhance knowledge in the field of Electronic Performance Monitoring (EPM), mainly with a focus on workers on construction sites [25]. Furthermore, the concepts of Digital Twins in Construction (DTC) and Digital Building Logbooks (DBL) are essential for registering physical elements that affect the performance of the buildings' operation [26], [27]. Finally, knowledge of construction product digital requirements leads to a Circular Economy and enhances actions that are beneficial to the environment [28]. Students need to have knowledge and skills both in terms of innovation and management. The focus on problem-solving and the ability to gather the requirements to perform process and systems analysis is crucial nowadays.

The main goal of the LBEs activities envisaged is the presentation and demonstration of new technologies in hardware and software applied to the construction environment. In the spectrum of "Construction Sites of the Future", the approach of EPM of construction work to assess productivity is relevant and can enhance performance in quality, costs, environment and safety [25], [29], [30]. Simulating construction tasks human-effort-demanding (e.g., sawing, hammering, painting) using electronic devices for monitoring the location and accelerations are meant to expose to students the on-site reality [31]. Also, the introduction to data processing methods (e.g., statistical analysis, artificial intelligence) shall focus on the interaction of data and humans. The EC3 (European Council on Computing in Construction) institutionalised the Human-Data Interaction (HDI) committee in 2020, given the topic's relevance [32].

BIM is a megatrend and most of its benefits are becoming more and more clear if the methodology can provide a streamlined use of relevant data [33]. In addition to modelling courses, the ability to understand the geometric model and its boundaries and the ability to perform practical experiments with digital platforms turned to data management is key [34]. The GrowingCircle project worked the paradigm of digital data for a circular economy, developing an awareness-level course for students and professionals achieving PBL [35]. It delivered competencies to understand better what Data Templates are, what benefits they can bring to the sector, and how they are related to the Digital Product Passport (DPP) that will be set on the EU Regulations Ecodesign [35]. Use cases of the digitisation of the sector's production chain products will allow the understanding of the concepts of DBL, DT and the Circular Economy [28]. Also, 3D speeded scanning using iPad-LiDAR technology will show new tools for built-up digital replicas of existing buildings ready for multiple uses [36].

3.2. Construction Sites of the Future: activities in the laboratory environment (LBE)

The first aim of this LBE initiative is the demonstration of innovative, practical deployments using hardware and software systems in practical and playful activities going through a lab-circuit. Where the students will perform everyday activities in civil construction, such as masonry, screwing and carrying materials, while wearing wearable devices (Accelerometers and Ultra-Wideband). At the same time, it is possible to monitor and visualise in near real-time the collection of these data related to accurate 3D location plus the 3-axis accelerations of the arms and legs. Fig. 2 (a) presents some devices and prototypes available for the CONSTRUCT-Gequaltec research group use. Fig. 2 (b) shows some students visiting the laboratory.

Fig. 2. (a) ICTs, devices, and prototypes, (b) Introducing ICTs to students at the lab.

For this purpose, a circuit was established to allow both testing hardware and software and to have students as "volunteer workers" to perform the construction activities, as can be seen in Fig. 3 (a). A circuit for Health and Safety (H&S) risks analysis was also developed (Fig. 3 b).

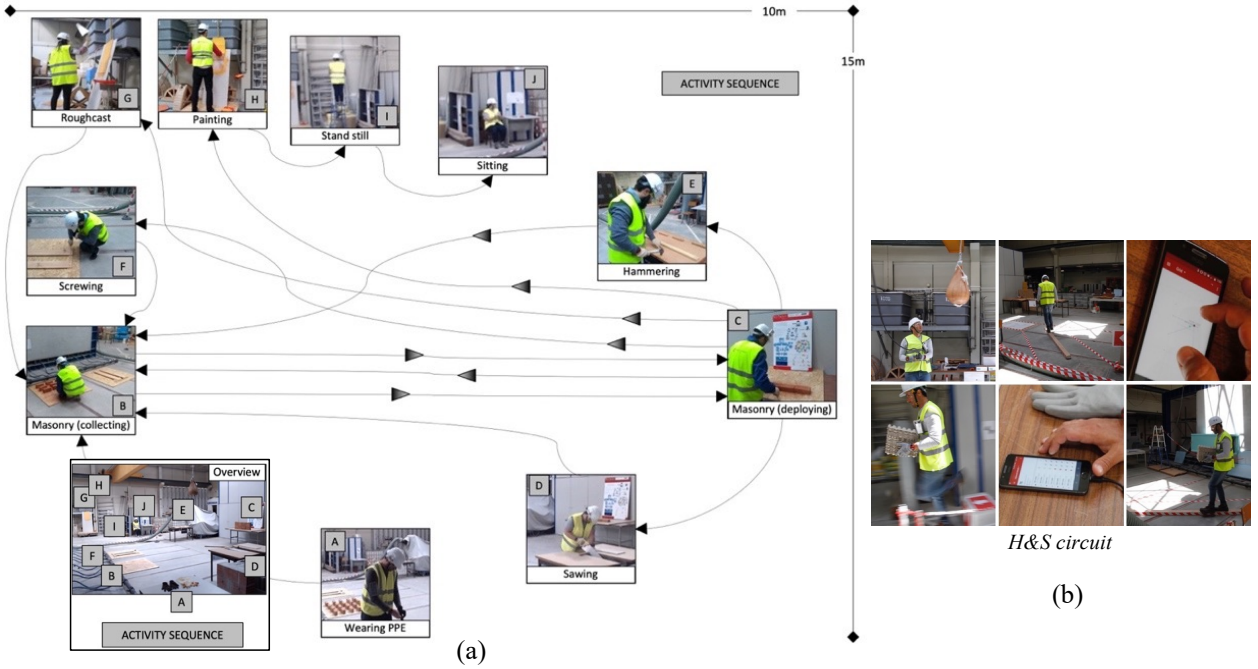

Fig. 3. Activities laboratory simulation: (a) construction tasks and activity sequence [31], (b) H&S circuit.

With this, students shall realise the technological uses and possible practical applications. Still, we seek to indicate to students that, yes, civil construction has fields of application for highly complex technologies. Also, the circuit performance allows students to "wear the shoes" of the craft workforce that is still the fundamental vector of tasks in the construction industry. This practical experience will show students how on-site jobs require high physical effort. The awareness of the real environment will allow students to understand the responsibility of claiming increased performance on-site. That scenario shall provide for the student's awareness of the relevance of making the shipyards work with less effort and more mechanised and what new methods can improve the process of the tasks. In this sense, IoT technologies to acquire data and AI tools for data analysis can be used to improve workers' on-site conditions. Empowering the next engineer's generation with 4.0 tools to develop projects targeting workforce benefits can contribute to the Civil Engineering 5.0 implementation. Theoretical support classes in the PM on developing innovative projects will complement students' skills to implement new actions and projects.

Students' verbal feedback indicates a new awareness of the demanding effort that on-site activities require. They realised that construction activities are compared to going to a gym or doing CrossFit training. Also, the students visually identified the logic and opportunities to collect data from path travelling and the hands and legs acceleration. Also, one master's dissertation and one PhD thesis were conducted on the theme of EPM.

3.3. Digital products catalogue and Digital Twins: project awareness (PBL)

Digital Twin is a data-driven concept meaning that it will live from data related to the product, system, construction, or built environment depending on the scale the DTC is being deployed [28]. One of the key aspects of pre-graduate education to capture students' attention is demystifying the concepts. Either to enable better understanding or to demonstrate that, although complex, the concepts can and should be seen from an incremental innovation perspective. Using analogies from other sectors and PBL demonstrations may help to improve overall perception and tackle resistance to change issues.

Different challenges on data management were prepared for students to test the usability of new technologies, see the added value of digital data, and be confronted with the difficulties of not having data or undefinition of its trustworthiness. Another case involved the 3D model already linked with DPP's to APIs to perform different assessments, such as energy performance calculations, Level(s) indicators, and definition of an asset management strategy, among others [35]. One case involved the digital product catalogue and the 3D model for students to set the links between the geometric objects and the DPP's based on Data Templates (Fig. 4).

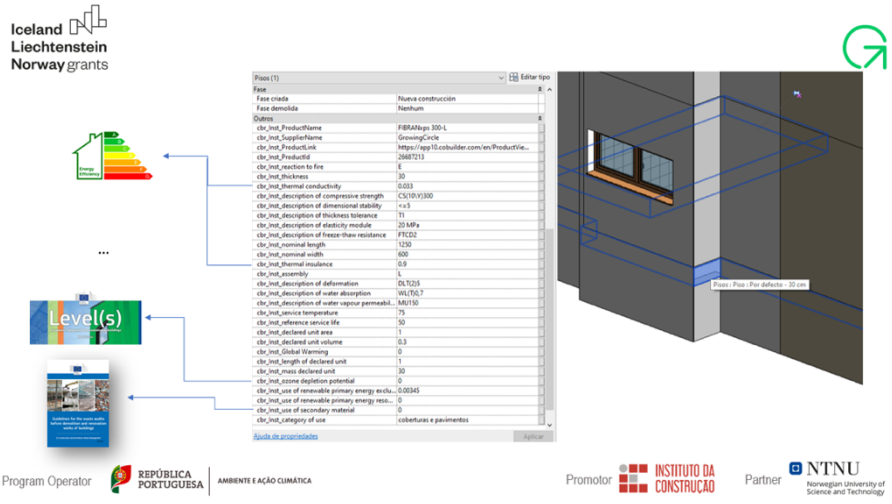

Fig. 4. Link between 3D modelling software and product catalogue to insert datasets in the object.

Data Templates and DPP are concepts not yet well-known by the industry. In the GrowingCircle project, we use BIM tools for Digital Data Management (DDM). The ability to have a common structure for data organisation is key to solving the equation, and this is the Data Template. Practicality is crucial to perceive the potential and benefits. As

well it is relevant for students to evaluate if that is of their interest or not. The ability to set a functional demonstrator with which students can engage can make a distinction. One of the GrowingCircle use cases presented and available involves a residential building under a refurbishment process [37]. A simplistic 3D model was prepared considering only the geometry and the different layers of products. A product catalogue was established with a set of real products.

Another case was set for students to identify data bottlenecks in the digital product catalogue, meaning datasets that would be needed for a defined assessment, but that are not being disclosed by the manufacturer as part of the product's technical content. Student's verbal feedback concerning the lessons learned and practical experience with the cases reveals that a clear understanding of the overall picture is gained and many theoretical topics from other disciplines make more sense with a vision of a real application. In this respect, the environment surrounding the EU Construction Products Regulation (CPR) and the EN harmonised standards for products became clearer. Students gain a different understanding on the challenges of BIM, namely the geometric requirements and how DPP's can streamline the effort of introducing datasets by hand. In association with this topic but out of the GrowingCircle awareness course, a specific case was set for students to work with an iPad with LiDAR scan abilities and set a speedy 3D model of a division, setting the roof, the floor, walls, windows, doors, and other relevant elements (Fig. 5).

Fig. 5. LiDAR scan process in iPad as part of a diagnosis process.

This aimed to test skills with portable devices and train different scenarios regarding the diagnosis of buildings in use where facing different situations, different annotations and procedures should be followed. Several outcomes are achieved when performing this single exercise. To start, students gain awareness on the relevance of performing site actions, namely the diagnosis prior to a refurbishment or to evaluate a building condition. Depending on the objectives of the diagnosis there are different information requirements, and these can be collected using the functionalities of a tablet. The identification and test on site of the best sequence to accomplish the outcomes and the acquisition of skills in working with the equipment is key for the results of the exercise and for the competencies that are needed in professional practice.

4. Conclusions and Further developments

The PBL and LBE initiatives experienced, supported by PM, IT and SB teaching, demonstrate a solid path into Education 5.0. With this, we planned gradually to incorporate and test these topics into the curricular units. Also, we envisage better orchestrating these actions over the multiple curricular units and courses, orienting a Civil Engineering 5.0 academic path.

The actions above-described targets develop students' competency to use innovation targeting to solve construction management issues. The active learning process envisaged should increase the learning outcomes. By the end, students

should be able to evaluate hardware and software solutions for construction management uses, define strategic goals for innovation development, and create a feasible scenario to conduct the projects and analyse the outcomes finally. Concerning The European Construction, built environment and energy efficient building Technology Platform (ECTP) research and innovation priorities classification [38], it is envisaged to contribute to the following areas: *Life Cycle Approach and Circular Economy (R&I 1.3)*, DDM are a fundamental part of LCA and circularity. *Healthy and comfortable built environment* (*R&I 2.3),* DDM guide a project with better energy efficiency outcomes. *Cleaner, faster, safer and more cost-effective construction, retrofitting & commissioning processes* (*R&I 3.1),* EPM on construction sites can increase H&S, and Productivity. *New contractual processes and partnerships for the construction sector* (*R&I 3.4),* the demonstration and application of innovative technologies are lacking in the field of civil engineering management. *BIM & Digital Twins for value chain integration, with focus on SMEs* (*R&I 4.2),* DDM is the basis of information for the DTCs.

Also, regarding the United Nations Sustainable Development Goals (SDGs) [39], the outcomes envisaged are connected to: *Good Health and Well-being (Goal 3)*, the students can target improvements of workers' H&S using innovative approaches. *Quality Education* (*Goal 4),* case studies and practical work provide opportunities for students active learning and thus increase knowledge retention. *Decent Work and Economic Growth* (*Goal 8)*, the idealised actions focus on developing the technical and cultural capacities of students and workers in the construction sector who may be affected by innovation actions, thus providing inclusion in this future 5.0 scenario. *Industry, Innovation, and Infrastructure* (*Goal 9),* it is vital to place Civil Engineering within the context of disruptive innovations and thus awaken in young students an entrepreneurial and innovative vocation. *Responsible Consumption and Production (Goal 12)*, students using DDM may be enabling future most sustainable choices/determinations in the design phase of a project. *Climate Action* (*Goal 13),* students using the DDM tool can future assess the expected emissions of each product, allowing choices that are less aggressive to the environment. *Partnerships to achieve the Goal (Goal 17),* via the integration between students, teachers, and companies to explore innovation in the civil engineering field.

Future research directions concern the development of more dissertations and theses in the construction companies' scenario using 5.0 solutions as proof of concept of the ideas developed over the classes. Also, it is an intended value to deliver civil engineers to the market with the knowledge and skills to conduct innovative projects within the scope of the construction industry's digital transformation.

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