Learning path for Construction 4.0 based on tinkering and STEAM

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ABSTRACT

This article describes the outcomes of a completed study of practice in civil engineering education. The study is aimed at infusing Construction 4.0 content to a Bachelor degree on Civil Engineering. A set of STEAM-rich activities are created in the form of an individual learning path. These activities are conceived with a threefold perspective: i) Construction 4.0-related, ii) STEAM vision by-design and iii) hardware-software independent (open-source, accessible, affordable). Cornerstone and capstone projects as well as a set of workshops represent some demonstrators of these activities. All these demonstrators are knitted together in a single path in that is pegged to the traditional curriculum The STEAM perspective provides completeness to the whole development. During the last two years, design, development and implementation of several demonstrators have been completed. Some results related to the application of some activities are already available. In the years to come, it is expected that an improved systematic deployment of such activities will allow assessing the evolution between tools, pedagogies and the needs of the sector. In this paper, the description of the activities together with the discussion on the potential of tinkering on Construction 4.0-based curriculum is addressed.

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1 INTRODUCTION

The process of digitization of the Architecture, Engineering and Construction (AEC) sector is relentless. In other sectors, this has represented a major change between players. AEC will certainly experience a significant disruption as well. The built environment sector is reaching maturity for leapfrogging to more efficient production, business models and overall, value chains. Both the natural as well as the built environments provide endless possibilities for digitization when it comes to linking physical assets and virtual models. A balanced path to digitization of a sector implies coordination between stakeholders. Academia where new generations of civil engineers are formed is called to be present and active in such scenario.

Technological advances in AEC are presently disrupting the sector. When applied in a coordinated and systematic way, these advances are much more powerful in efficiency. The coordination between the construction realm and its virtual counterpart is generating a framework in which a tripod of three themes can be identified

- Industrial production (prefabrication, digital fabrication, additive manufacturing, offsite manufacture and robotic assembly).
- Cyber-physical systems (autonomous systems, digital twins, smart infrastructure).
- Digital technologies (BIM, extended realities, interoperability, cloud computing, blockchain, AI, computer vision, etc.).

In AEC, proposals for infusing automation and robotics within the curricula have been discussed for some decades [1]. On the other hand, the adoption of BIM in civil engineering curricula is a matter of survey, debate and systematic scrutiny [2]. When it comes to cyber-physical systems in AEC classrooms, developments are also identified [3-4]. Within «de las MATES al STEAM », an educational project developed between 2019-2021 at the School of Civil Engineering at the Universitat Politècnica de Catalunya in Barcelona, Construction 4.0 and STEAM were put together. The initial conundrums at the onset of this development were : How prepared are existing civil engineering curricula for this disruption?. How is digital and automated fabrication being infused in AEC classrooms? Are AEC students prepared enough for understanding cyber-physical systems conceived for the natural or built environments ? What is the level of maturity of BIM-based curricula in AEC. An extensive academic literature review allowed identifying academic practices worldwide as well as gaps within curricula [5-8].

This paper shows the key takeaways of “de las MATES al STEAM”. The project resulted on the design of set of activities for embedding Construction 4.0 concepts within a civil engineering curriculum. The development of these activities was conceived by-design using a STEAM, tinkering perspective. Findings related to the attractiveness of this perspective in AEC students are also described. The activities are knitted together in the form of an individual learning path that reinforce concepts of traditional curricula in civil engineering with the use of Construction 4.0 open, accessible and affordable technologies.

2 LEARNING PATHS

Standard degrees are necessarily complemented with personal learning paths. This need is embedded into the DNA of intrinsically motivated learners. Civil Engineering Schools may or not have a vast array choice of optional courses. A complementary personal learning path is a learner-centered approach that emphasizes learner-specific goals and objectives, as well as preferences that a learner elects on their own. Students comprehend their personal learning pathways through several ways such as: (i) the identification of optional courses through preference of topics that are the most relevant to student’s current or future professional activity, (ii) use of accountable side-courses, workshops, capstones, hackathons or (iii) development of internships and academic exchanges.

3 LEARNING PATH IN THE PROJECT “DE LAS MATES AL STEAM”

The proposed learning path for the infusion of Construction 4.0 activities within a standard curriculum is illustrated in Fig. 1. By-design, the path is conceived for including the depicted tripod of themes of Construction 4.0 with a STEAM approach. Dissecting this illustration, one identifies several bullet points:

- In the 1st academic year, cornerstone projects related to coding are proposed. These projects are conceived for the sake of introduction to visual and geometrical programming, which are fundamental for subsequent developments. The programming content of the projects is also aligned with the actual syllabus of regular courses of Calculus, Algebra and Geometry. Pilot implementations within formal courses have already been taken place at the School in the last three years. The principal STEAM components of such projects are Maths (M) and Arts (A).
- In 2nd and 3rd year, the activities consist of a set of workshops. Different themes of Construction 4.0 such as Automation and Robotics, Digital Fabrication, BIM or IoT represent fertile topics for the generation of workshops

that can be updated year by year. The principal STEAM components of such projects are Science (S), Technology (T) and Engineering (E). These workshops are self-contained but if students are acquainted with the content of the cornerstone projects, their learning curve as well as their achievements are boosted. These workshops are conceived for 1 ECTS. If this credit needs to be recognized to the students by the system, the minimum number of hours of these activities with proper compeletion is 12.

- In 4th year, a capstone project allows closing the loop by integrating all (S)(T)(E)(A)(M) components in a single activity. Ideally, this represents a fertile ground for more ambitious projects with a multidisciplinary perspective. Its application may range between individual final project for the Bachelor degree to more multidisciplinary projects in which students from electronics, computer sciences and civil engineering may converge. The former option has already been experienced at the School whereas the latter requires more coordination between educational centers at University levels.

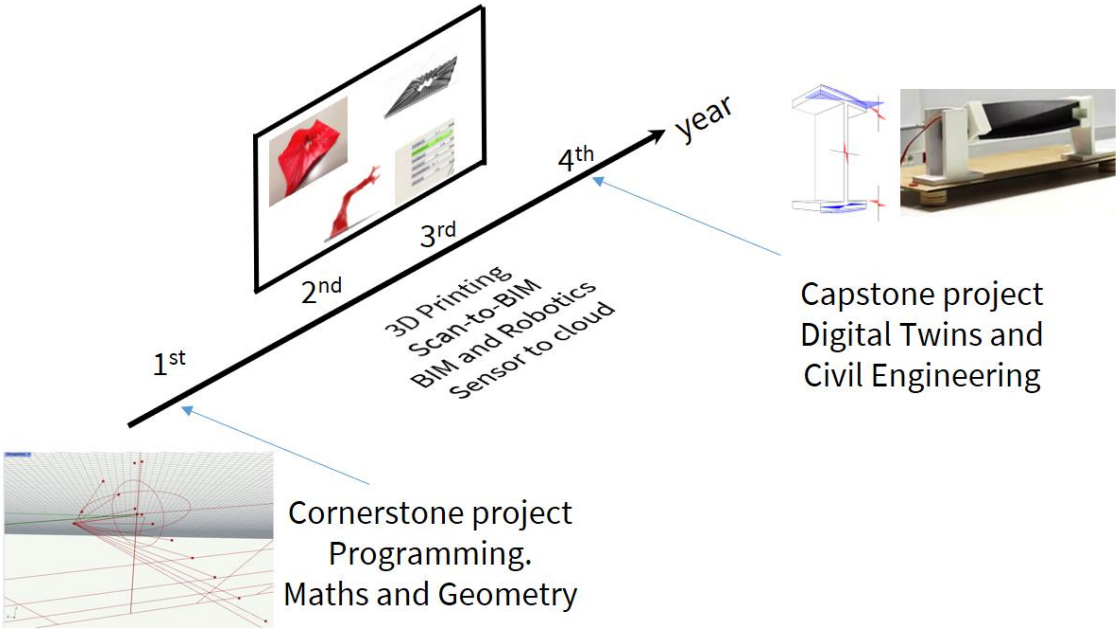


Fig. 1. Schematic view of the proposed set of activitis within the civil engineering timeline

4 LEVEL OF IMPLEMENTATION OF ACTIVITIES IN RECENT YEARS

In the last years, many of those activities have been implemented at both Bachelor and Master levels. In the following, a brief description of these implementations together with results obtained so far.

- Cornerstone projects: The cornerstone projects are established as activities related to Calculus and Computational Geometry for 1st year students. These activities are conceived for the sake of exposing our civil engineering students to the development of computational applications using basic concepts of mathematics and geometry. One of the already implemented projects (2020,

2021, 2022 editions) is related to the development of visual applications using functions and derivatives. An introductory programming challenge is optionally proposed to students. For different editions, students have or not received a reward on the total grade of the courses if the challenges is achieved. The application of the programming activity in the 1st Edition (2020) coincided with the global lock down and the participation peaked 98%. In subsequent years participation has lowered to 50%. Applied introductory programming are always useful and necessary for civil engineering students due to their uneven prior acquaintance with coding skills. The project is aimed at reinforcing concepts of differentiation throughout a hands-on coding activity. The formal Calculus syllabus (M) including derivatives is illustrated by students by designing a beautiful visual application (A).The challenge of the activity is: For a given implicit function, an interactive visual application must be developed. Details on the developments the can be found in [9] and an illustration of the developments is presented in Fig. 2.

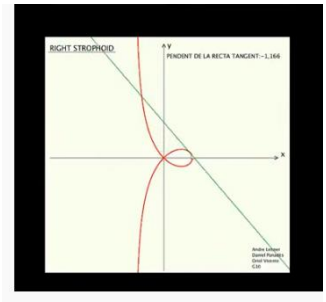
- Workshops:

    - ***Sensor-to-cloud***, a workshop already implemented within formal courses at the School, represents a journey from physical-to-virtual. AEC classrooms are filled with countless attempts of understanding both natural and built environment. Practically every single magnitude studied in AEC is prone to be measured with sensors. Acquiring basic skills on measurement is thus, very relevant. This activity has been implemented in varying forms by the educator since 2015, when electronic prototyping platforms such as Arduino were first used in the School. The activity has already reached maturity and present editions are developed in 12 hours (1ECTS). All participants are provided with sensors, microcontrollers (open, accessible and affordable) and an account to a cloud-based IoT platform developed at the School. The development of this activity has evolved rapidly and different cloud technologies have been tested [10] in the classroom.
    - ***3D printing*** (prepared) represents a journey from a virtual space to the materialization of an object. The workshop may provide not only a better understanding of the virtual space but also, it sets some realisms to the boundaries provided by 3D printers. This workshop is prepared yet it has not yet been implemented. The duration of the activity is 12 hours (1 ECTS).
    - ***Scan-to-BIM*** (1st attempt done) represents a journey from physical magnitudes to a BIM-compatible space. The workshop shows one of the most promising technologies for the built environment, which is laser scanning. The workshop provided a real time illustration of how points are measured with sensors (lasers, accelerometers in this case) and virtualized with computational geometry tools. In AEC, the use of

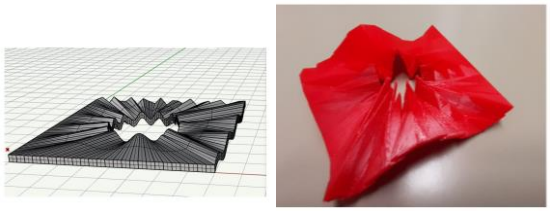
"as-built" entities in BIM software presumes an understanding of these principles. In 2022, the 1st Edition of the workshop was implemented. A short 2 hours experience in which students played with spheres, scanned the spheres and subsequenty, identified the spheres in a parametric-generative modelling tool.

- **BIM-to-Robotics** (under preparation) represents a journey from virtual to physical within a BIM-compatible space. The workshop introduces the potential of automation in construction with accessible and affordable equipment. It illustrates to AEC students what has been more traditionally present in other engineering branches, instrumentation and control of machines.

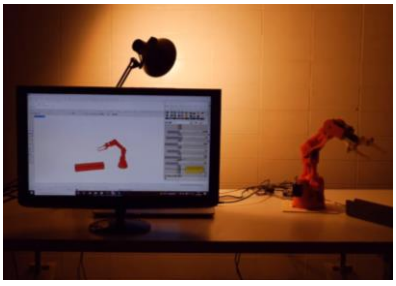
- Capstone projects: Construction of a digital twins of an asset represents a comprehensive activity that encompasses all previous developments. It represents an information construct in which both the development as well as its systematic usage are didactic. The flow of information goes from physical-to-virtual and vice versa. Sensors are needed, Virtual spaces are needed and a seamless communication between both realms is required. Digital twins also represent a promising conception in the built environment called to help in a better understanding and management of the assets at design, construction and maintenance stages. Five individual final projects at Bachelor levels have been successfully implemented since 2016. Ideas for expanding these projects to diverse teams (electronics, computer sciences, civil engineering) require further coordination between Schools. A sample of applications are found in [11,12]



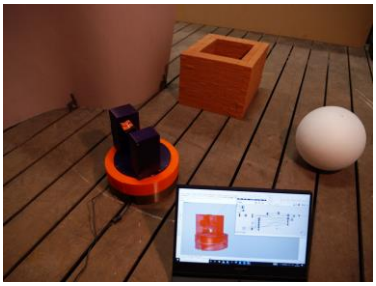
1st Year. Cornerstone Project. Calculus and Interactive Coding



2nd Year. 3D Printing and Maths



3rd Year. BIM and Robotics



4th Year. Capstone Project. Digital Twins

Fig. 2. Developments for some of the depicted activities

5 DISCUSSION AND FUTURE IMPLEMENTATIONS

Developments and findings of the recently finished educational project “de las MATES al STEAM” are depicted. The project The following key takeaways are worth pointing out:

- The market-driven driving forces for digitization of the sector are erecting a frame labelled as Construction 4.0. Digital Industrial Production (from virtual to physical), cyber-physical systems (from physical to virtual) and an established framework for digital technologies (BIM) represent the tripod of this definition.

- It is observed that Civil Engineering students are lacking specific knowledge for their proper inclusion in the Construction 4.0-related job market. This aspect is being addressed by educators and schools at a rather slow pace. Civil engineering schools are unevenly integrating Construction 4.0 activities in existing curricula. This lack of content is identified in many aspects such as the use of sensors and measurements, the use of BIM-enabled computational tools and the real time connection between the physical and the virtual realms. In addition, coding and computational geometry tools are required skills for Construction 4.0 related activities.

- Following the identified tripod, a Construction 4.0 learning path for standard degrees on Civil Engineering has been proposed. Cornerstone projects, workshops and Capstone projects were conceived with the intention of filling the Construction 4.0 identified gaps. All activities were knitted together using a (S)(T)(E)(A)(M) educational approach. Cornerstone projects are intended to foster motivation at early stages of the degree. Maths (M) and Arts (A) are blended together in hands-on activities. Subsequently, the set of workshops are intended to provide necessary knowledge on different engineering (E) technologies (T) with a critical scientific approach (S). These workshops are not limited to those proposed herein. Thus, the capstone projects result on integrators of all aspects dealt with along the degree. A (S)(T)(E)(A)(M) development of digital twins for civil engineering represents an accessible, affordable and scalable vehicle for infusing Construction 4.0 in civil engineering classrooms.

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