



Specification of the BIM-enabled Learning Environment

**By: Tallinn University of Technology, Estonia
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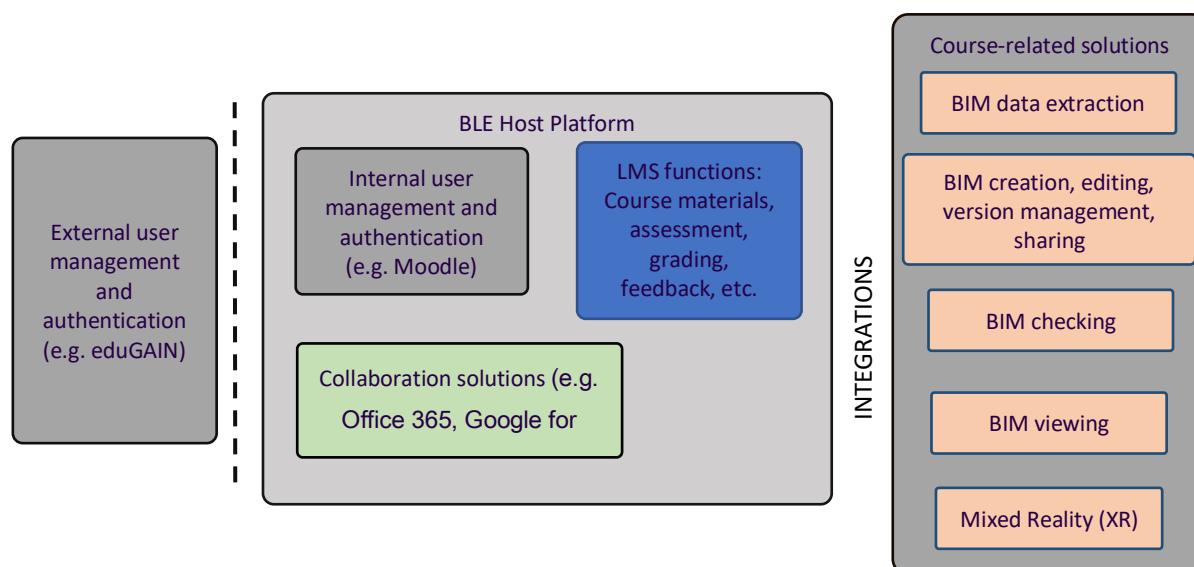


Executive Summary

Intellectual Output 1 of the BIM-enabled Learning Environment for Digital Construction (BENEDICT) project is aimed at specifying the requirements for a BIM-enabled Learning Environment (BLE). This document reports the development of the BLE specification through:

- Surveys of existing educational technological systems / platforms at the 3 partner universities.
- Defining functional requirements for the BLE through the analysis of existing BIM-enabled courses and 31 interviews of experts in the 3 partner countries.
- Refinement and validation of the functional requirements at a stakeholders' workshop.
- Delineation of suitable technical solutions to enable the defined functionalities.

The resulting system design for a prototype BLE is determined as shown in Figure 10 of the report (repeated below for readers' convenience):



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1 Introduction

1.1 Background and purpose

Digitalization is driving changes in the Real Estate and Construction (REC) sector. A central feature of this digital transformation is Building Information Modelling (BIM) which refers to the integrated digital representation of all building-related information. The BIM-enabled Learning Environment for Digital Construction (BENEDICT) project is aimed at leveraging the emerging possibilities of BIM to enhance the education of REC professionals by developing an innovative, BIM-enabled Learning Environment which offers more realistic, immersive and integrated learning experiences.

The BENEDICT project is an Erasmus+ strategic partnership between the Department of Civil Engineering and Architecture at Tallinn University of Technology (Estonia), the Civil Engineering Unit of Tampere University (Finland) and the Department of Architecture at the University of Bologna (Italy). A range of REC education stakeholders including teachers and learners, representatives of the REC industry and bodies responsible for BIM standards are participating in the project. The project activities follow a simple logic – step 1: developing a BIM-enabled Learning Environment (BLE), step 2: creating content for it and then step 3: enabling people to use it (see Figure 1). These steps are to be achieved through six intellectual outputs, 3 multiplier events and a joint staff training event.

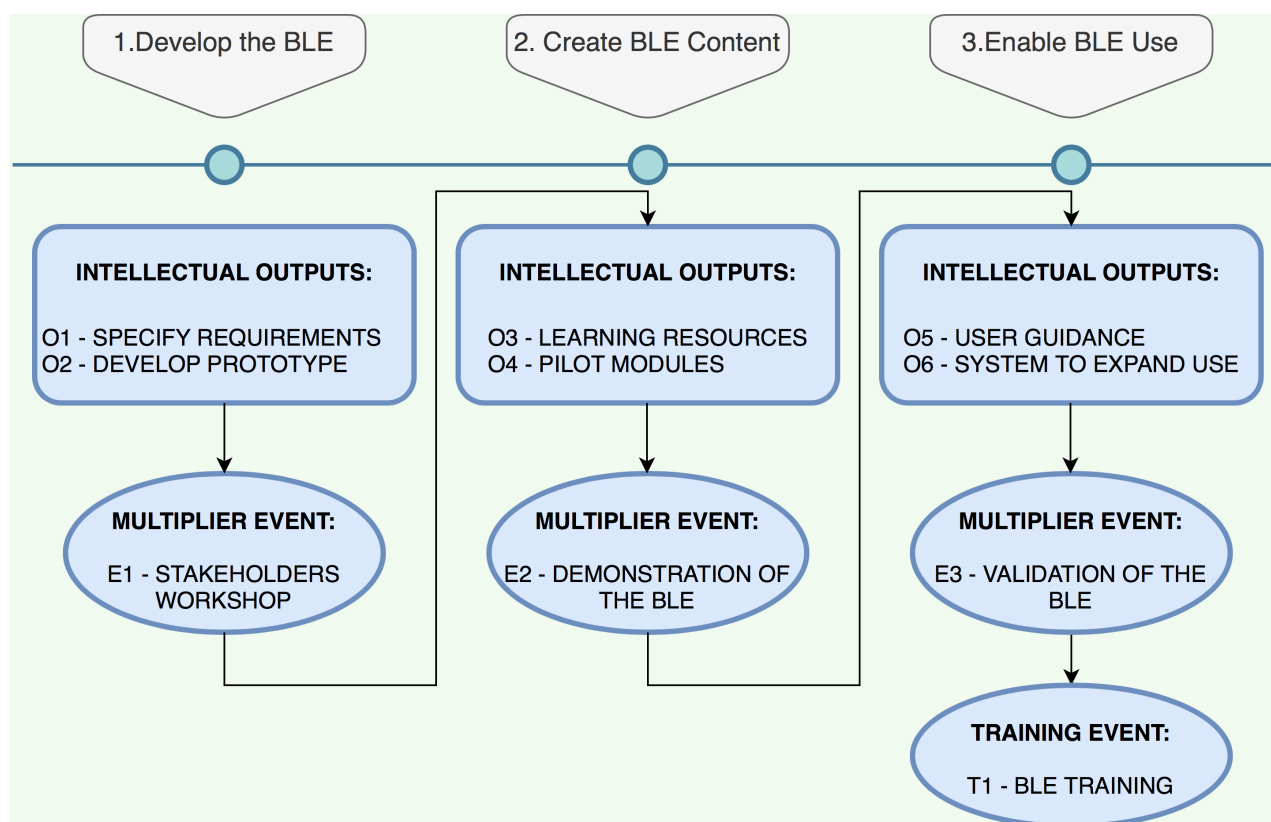


Figure 1: BENEDICT Project Process Diagram

The first of these Intellectual Outputs involves the specification of requirements for the BIM-enabled Learning Environment and this document reports the process and findings from this first Intellectual Output (Specification of the BLE) which was carried out during the first year of BENEDICT project implementation.

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1.2 Objective

The objective of this Intellectual Output was to develop the functional and technical requirements for the BIM-enabled Learning Environment (BLE). In our preparation activities for the BENEDICT project, we had jointly developed the BLE concept at a theoretical level. As individual organisations, we had also piloted a small number of BIM-enabled learning experiences within the framework of our existing teaching programs. Together, these provided us with a solid starting point for defining the functional and technical requirements for the BLE (Intellectual Output O1) which, in turn, will be the basis of developing the actual BLE (Intellectual Output O2).

1.3 Methodology for specification development

A desk study of related initiatives and applicable standards relevant to the proposed BLE was first undertaken. An exercise to identify and compare the existing platforms and systems in use at the three partner universities was then carried out to ascertain the education-technological systems contexts into which the BLE should integrate.

An initial list of functional requirements was compiled by analyzing existing courses or learning experiences which had elements of BIM-enabled learning (one such case study being analyzed from each partner university). The functional requirements were further elaborated through a series of 31 interviews of stakeholders connected to education and training throughout the REC sector and in three countries (Estonia, Finland, and Italy).

The identified functional requirements were then subjected to a validation exercise in the form of an online workshop where the functional requirements were presented and participants were asked to rank them in terms of their relative importance and to add any further, missing requirements.

The list of validated functional requirements was then assessed by key informants in each country who commented on how these functional requirements could be technically delivered. The feedback from these key informants was compiled and an emergent technical solution in the form of a system concept design for the BLE was proposed. These process steps, their logic and outputs are shown in Figure 2:

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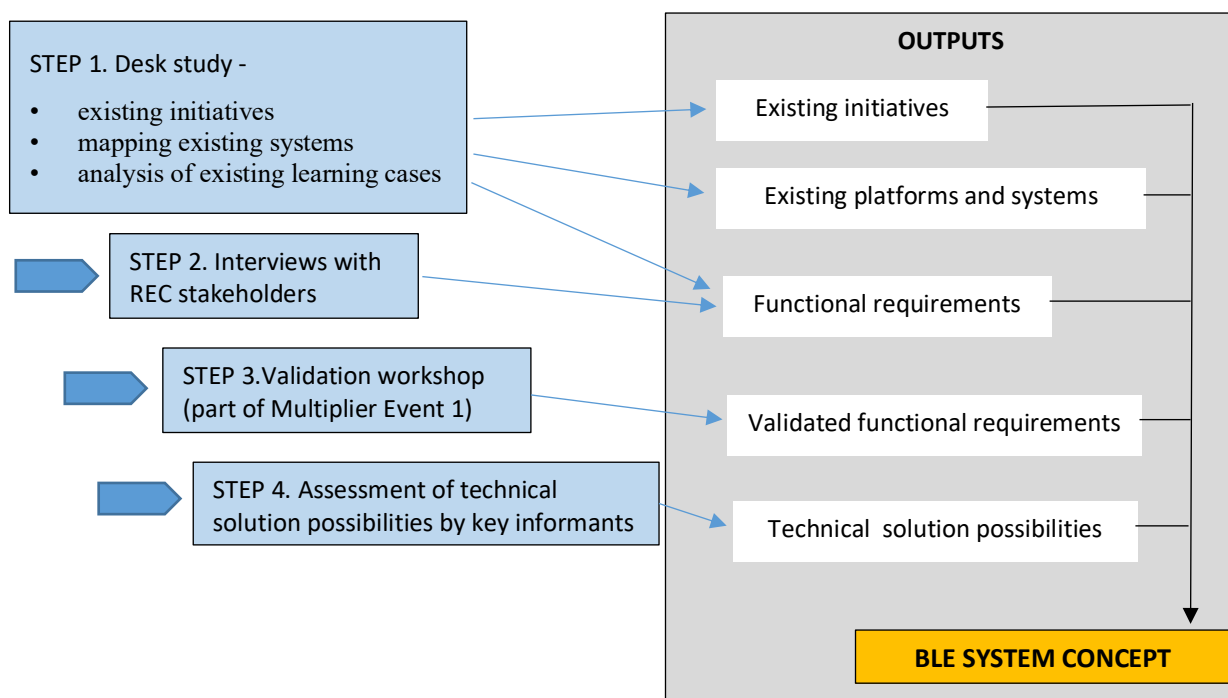


Figure 2: Methodology for Defining BIM-enabled Learning Environment (BLE) Requirements

1.4 Structure of the specification report

In section 2 of this report, existing related initiatives and applicable standards are very briefly reviewed. Section 3 reports the results of investigating the project partners' existing systems and platforms. Section 4 focuses on the initial list of requirements for a BLE based on case studies of existing BIM-enabled learning activities at the partner universities. Section 5 contains the findings from stakeholder interviews in all 3 partner countries and the final, validated list of functional requirements. Section 6 reports the assessment of technical solution possibilities to provide the identified functionalities. Finally, section 7 presents the proposed system concept for the prototype BLE platform.

2 Review of existing initiatives and standards

Reviews were carried out of the academic and grey literature with respect to identifying existing initiatives and standards considered to be potentially relevant to the development of a BLE platform. For the purpose of this report, the findings from these reviews are very briefly summarised below as, in hindsight, they had relatively little bearing on the development of the BLE platform in comparison to the systems in use at the partner universities and the functional requirements identified.

Interest in BIM-based education has been growing over the last decade with most study programs incorporating BIM awareness creation and educating students and trainees on how to use different BIM-related software packages (e.g., Revit, ArchiCAD, etc.) for model viewing, creation, viewing, simulating, data sharing or coordination (e.g., Ren

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& Zhang, 2014; Comiskey et al., 2017). Courses typically highlight the benefits and barriers of BIM and the reasons for BIM adoption in the industry (e.g., Ahn et al., 2013; Puolitaival & Forsythe, 2016), and progress to BIM knowledge and authoring/manipulation skills (e.g., Ghosh et al., 2015). Beyond developing BIM software skills, BIM technology has also been used to impart other learning such as coordination, collaboration, communication, and interpersonal relationships among students, etc. (e.g., see Barham et al., 2011; Bozoglu, 2016; El Zomor et al., 2018; Zhao et al., 2015; Ghosh et al., 2013).

BIM-enabled learning environments have been experimented with over the past decade. Ku and Mahabaleshwarkar (2011) proposed a BIM interactive model (BiM) – a platform combining a virtual environment (Second Life) with BIM for learning purposes and proposed a theoretical web-based virtual world for engaging construction stakeholders in real-time social interaction. Their intention is to supplement construction education with intelligent 3D BIM models in order to overcome the limitation of location-based learning and make it accessible to anyone with an internet connection. Shen et al. (2012) used the 3D-UNITY game engine to create a web-based training environment for HVAC rehabilitation and improvement using a BIM model. In contrast to Ku and Mahabaleshwarkar (2011) BiM proposal, Shen et al. (2012) argued that game engines have been sufficiently developed for BIM interoperability thereby making game creation cheaper and easier and demonstrating how BIM could be leveraged for teaching. More recently, Zamora-Polo et al. (2019) have argued that, for the education of engineers, BIM can be considered a Virtual Learning Environment (VLE).

With regard to potentially applicable standards, the review identified a wide range of standards that could be applicable in the context of a BLE – with respect to common data environments, virtual learning environments and open BIM standards. Following from the general principles that had been adopted from the start of the project, specifically with respect to the BLE being an open platform, the single most important standard was the Industry Foundation Classes (IFC) standard relating to open BIM which was effectively agreed on at the start of the project. Further standards and protocols would, in practice, follow from subsequent decisions made in terms of the type of platform and system design of the BLE.

3 Overview of partners' existing platforms and systems

3.1 Learning Management Systems and Virtual Learning Environments

TalTech

TalTech is using their own server space for a Moodle and also for BigBlueButton (web-conferencing tool). MS Teams is used corporate-wide for meetings and as a collaboration / communication platform for delivering online learning.

A further Moodle-based platform which is considered in this mapping exercise is the REGARD virtual training platform which is a Moodle-based platform established to host Massive Open On-line Courses (MOOCs) in the context of a current Erasmus+ funded REbuildinG AfteR Displacement (REGARD) project since it is currently being developed by the same TalTech team which is engaged in the BENEDICT project and is relevant to BENEDICT in terms of its characteristics.

- TalTech: Moodle (www.moodle.org), version 3.9+, separate server hosting
- TalTech: BigBlueButton (<https://bigbluebutton.org/>), separate server hosting
- TalTech: MS Teams
- REGARD virtual training platform (<http://www.disaster-resilience.net/knowledgehub/course/index.php>), external to TalTech.

TAU

Tampere University (TAU) is using their own server space for a Moodle. MS Teams and Zoom are used corporate-wide for meetings and as a collaboration / communication platform for delivering online learning.

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- TAU: Moodle (www.moodle.org), version 3.5
- Panopto
- Kahoot!

UNIBO

The University of Bologna is using Virtuale (virtuale.unibo.it) as a Learning Management System (LMS) and Virtual Learning Environment (VLE).

Virtuale is a customized version of Moodle, where the customizations are mainly related to:

- communicating with University Directory Service d'Ateneo (DSA – it's the Academic Active Directory) and other academic database sources.
The interaction between Virtuale and the academic databases is fundamental since University of Bologna is potentially offering more than 4500 courses each semester. Several information about the courses (course name, course area, type of degree, course teachers, collaborators, etc.) is passed from the academic databases to Virtuale.
- using a federated identity provider to allow the access to Virtuale to more than 90.000 students and about 3.000 professors.

The current Moodle version on which Virtuale is based is the 3.9 release. Virtuale is hosted on a Microsoft Azure cloud service.

Some organizations (i.e. Centro Linguistico di Ateneo – CLA), due to their specific needs, are using a different customization of Moodle, that is called e-cla. With Virtuale, e-cla shares the same federated identity provider. Being addressed to a smaller number of users, e-cla is self-hosted.

A further VLE is a platform established to host Massive Open On-line Courses (MOOCs). At the University of Bologna is called Book (uniBO Open Knowledge - book.unibo.it) and it's built on the top of Open EdX (<https://open.edx.org/>). At the moment, Book is self-hosted.

For remote / hybrid learning the university of Bologna is using Microsoft Teams to broadcast and occasionally recording lectures.

3.2 Other Platforms and Systems

TalTech

TalTech also has a bespoke Study Information System for course information and registration, student declarations and results, timetabling, room bookings, etc. This Study Information System is in its second generation and is referred to as OIS2:

- TalTech: OIS2 (custom system) (www.ois2.ttu.ee)

Further web-conferencing solutions are also in use at TalTech but on a more limited scale. These include Zoom web-conferencing and, in addition, WORKSUP (www.worksup.com), a virtual conference and event platform developed at TalTech. However, it is unclear whether these are directly relevant to BIM-enabled learning and the BENEDICT project except as possible platforms for hosting project-related events. They are not considered further in this mapping exercise.

TAU

TAU also has a bespoke Study Information System for course information and registration, student declarations and results, timetabling, room bookings, etc. This Study Information System is referred to as SISU:

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- TAU: SISU (custom system)

TAU also has a bespoke Electrical Exam Platform (Exam) for organizing and performing electrical exams for courses.

- TAU: Exam (Electrical exam platform)

Further web-conferencing solutions are also in use at TAU on a significant scale. These include Zoom and MS Teams web-conferencing. Microsoft O365 software suite is also in use at TAU. These are not considered further in this mapping exercise.

UNIBO

In more specific contexts, the University of Bologna uses other web-conferencing solutions. These include Zoom web-conferencing (unibo.zoom.us), used especially during exams or specific courses, and Adobe Connect, currently in disposal. However, it is unclear whether these are directly relevant to BIM-enabled learning and the BENEDICT project except as possible platforms for hosting project-related events.

3.3 Platforms and Systems Integration

TalTech

Currently, the TalTech: Moodle and TalTech: BigBlueButton are integrated in the sense that the BigBlueButton plugin has been installed in TalTech: Moodle so that BigBlueButton is available as an activity option within Moodle.

Moodle and MS Teams can be integrated in both directions as Teams-related plugins in Moodle or in the sense of a Moodle integration into the MS Teams platform. In TalTech's case, the current extent of integration is that of the Teams Meeting plugin having been installed in the TalTech: Moodle.

In addition, there are future plans for integrating the TalTech Study Information Systems (OIS2) with the TalTech: Moodle to enable participant /course enrolment lists to be generated automatically from OIS2 and send final grading from Moodle into OIS2.

TAU

Currently, the TAU: Moodle and TAU: Panopto are integrated in the sense that the Panopto plugin has been installed in TAU: Moodle so that Panopto is available within Moodle.

Moodle and MS Teams can be integrated in both directions as Teams-related plugins in Moodle or in the sense of a Moodle integration into the MS Teams platform.

In addition, TAU Study Information Systems (SISU) is integrated with the TAU: Moodle to enable connect participants automatically from SISU to TAU: Moodle.

UNIBO

Virtuale (moodle) and Teams are strongly integrated with academic data sources. In Virtuale, courses and enrolments are automatically generated.

Since Virtuale is an academic-wise environment, every change or addition is impacting on 5 campuses, 93 Degree courses and 32 Departments. It's difficult to introduce customizations or add-ons if these variations do not represent a global advantage for the whole population of students.

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3.4 Platforms' and Systems' Descriptions

3.4.1 Moodle (common to all (TalTech / TAU / UNIBO) installations)

Platform / System general attributes

Moodle is an open source platform where customizations are mainly made in the user interface layout. TalTech Moodle has a customized user interface and some customization in terms of added standard plugins (not coming with a standard installation but accessible through Moodle plugins list).

Compatibility including cross-platform compatibility at macro (different institutions) and micro (desktop versus mobile phone) levels

Courses can be exported/imported through standard Moodle course exports. Moodle quizzes can be imported/exported through standard list of supported formats. Supported export formats like Aiken format, GIFT format, Moodle XML format, XHTML format. Supported import formats include: Aiken format, Blackboard, Cloze, Examview, GIFT format, Missing word format, Moodle XML format, WebCT format.

Teachers can export their courses out and import those into other Moodle systems (including other schools/universities). Some problems may raise up if the Moodle versions are different but usually it is at minor level, meaning that 3.8+, 3.9+ or 3.10+ versions are used, and compatibility is ensured as long as no special plugins are incorporated). As Moodle works in different web browsers the compatibility is ensured for various operating systems. There are differences or special requirements if some assignments do need an offline work (using some engineering platform/software) which is only available for Windows or iOS. Mobile phone support is delivered with standard Moodle apps from Google Play / Apple App Store (like Moodle for Android or Moodle for iOS).

Learning Management System and Virtual Learning Environment standards

Assuming that all applicable web standards are in place, key additional, learning management system's (LMS) standards and guidelines applied in Moodle include:

- (1) Web Content Accessibility Guidelines (WCAG): <https://www.w3.org/TR/WCAG21/>
- (2) Sharable Content Object Reference Model (SCORM): <https://adlnet.gov/projects/scorm/>
- (3) IMS learning tool interoperability (IMS LTI): <http://www.imsglobal.org/specs/ltiv1p0/implementation-guide>
- (4) Open Source Initiative applied like GNU General Public License or similar:
<https://www.gnu.org/licenses/gpl-3.0.html>
- (5) Open Badges integration for learning verification: <https://openbadges.org/>

Users - Accessibility

(TalTech & TAU) To participate in Moodle, an account is needed which can be manually created or connected with University UNI-ID which is unified digital ID for all university-related digital systems/access. If a custom user account is used (for continuing education purposes), a user needs to define their personal (national) identification code to eliminate double-accounts.

Virtuale (UNIBO Moodle) is compliant to the Web Content Accessibility Guidelines (WCAG): <https://www.w3.org/TR/WCAG21/> and scored 87% on [webaccessibility.com](https://www.webaccessibility.com). Minor violations emerged

User types and their roles

Student, teacher roles (TalTech & TAU). Student, teacher, collaborator, admin roles (UNIBO). But courses can be opened for public view as well (no Moodle account is needed, so-called guest user access). Special user accounts are available for institution-wide reviewing of courses. User accounts should be made by the user. User should enroll to each course separately (using enrolment key, which also can be group based). User is not able to unenroll, only teacher can do that (to avoid hop ins/outs). No manual registration is allowed (feature disabled) by the teacher even

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if the user account exists (GDPR requirement). User support is divided in the following steps: student > teacher > educational technologist > Moodle administrator

User registration and orientation

TalTech & UNIBO: Each semester starts by self-enrolments into selected courses. Special grouping can be added by the teacher or students can select additional groups to create project groups in some course. User registration is defined and supported by the course teacher.

TAU: Students are assigned to the TAU: Moodle courses based on their registrations in the Study Information System (TAU: SISU). Students and teachers can be also registered for the course manually. User registration methods are defined and supported by the course teacher.

Communication channels

Teacher creates communication channels usually course-based or their own preferences. Minimum requirements are defined by the Moodle course level (which tools should be used) and/or is connected with general rules of communications in between student and teacher. Course-related communication can be delivered through Moodle in the form of messaging, forum posts, feedback to different activities, etc.

Features encouraging student active and collaborative participation in and reflection on learning

Standard Moodle capabilities can be used to message, engage the student throughout the course. Group-based activities can be created in where the assignment is uploaded as a group-based but each participant should confirm the upload separately (not uploading, just confirming) which can be connected with previous activities and can be controlled by Moodle. In those situations, students in one particular group become their own and each-other's motivators.

Assessment and evaluation of students' outputs

It is a teacher's choice how the final grade is formed throughout the semester. Will there be an exam, final work or summed up from different assignments (including online assignments and/or face-to-face evaluations). For a Moodle course level (b) or (c) it is usually fully 100% online evaluation (if possible, as some works may be still evaluated face-to-face). Grades in the Moodle grade book then have to be exported (manually at present) into the Study Information System (TalTech: OIS2; TAU: SISU) which is the official system for registering the performance/study program of all students.

Content - Organisation of content - Courses (or other meso units of learning: Program / Project / Module)

TalTech & UNIBO: Moodle based workflows are used, for example: (a) courses can be restarted each semester for a new study group; (b) courses can be reset (all previous activities/results deleted) and/or regenerated (recovered) from the backup file; (c) courses can be exported out, as well as imported from another Moodle system.

For new Moodle courses, basic course templates are available which helps to deliver the course main content as defined by our regulations. Those regulations define three levels of course types: (a) basic e-supported learning, usually carried out through contact hours but enhanced with a Moodle course page; (b) e-learning course that should fill additional engagement components and can be carried out as an e-learning course only; (c) e-learning course that includes enhanced media content, special videos and fulfils the separate, average minimum feedback level from previous students. Therefore, Moodle is used for different study purposes. Currently there are around 1200 level (a) courses. All compulsory subjects are required to have level (a) Moodle course page.

TAU: Teacher can import content of the course with import-function from other course implementations which he or she has appropriate user rights. For new Moodle courses, basic course templates are available which helps to deliver the course main content.

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Learning resources types and hosting / editing requirements

Various activities can be created and connected into Moodle course with a separate engagement focus areas. Standard learning resource types are used; some Moodle plugins are used as additional possibilities (which do not belong to standard installation). Key learning material types used are text, uploaded files, videos. Editing is usually made by the teacher who is also responsible to include copyright information/references. Modern learning resource types are fully supported with the latest Moodle installation (currently 3.9+ is used which includes for example H5P content support).

Legal - Intellectual property, copyright, data protection, etc.

All course materials created by the appointed teacher belong to University. All copyright rules should be used if referred material is used. Data protection is aligned by the general GDPR. Each user who creates a Moodle account should accept those rules before they can use the platform.

Quality assurance - evaluation and feedback opportunities for all users

Students can evaluate throughout the course using Moodle standard tools / feedback forms which helps to carry out student self-assessments as well as comparing their activities at different scales (subjective, objective scales). Moodle course final feedback is usually filled in voluntarily by each student. In here teacher can create the feedback questionnaire which helps them to improve the course delivery, content for future presentations. Moodle feedback can be created with a username recorded, anonymously or leaving the choice open if a user wants to share their username they can input it into special fields.

3.4.2 BigBlueButton (TalTech)

BigBlueButton is a virtual classroom application in the form of a Moodle plugin that is integrated with the TalTech: Moodle. It enables sharing of audio, webcams, screens, multi-user whiteboards, polling, messaging and more.

3.4.3 Panopto (TAU)

Platform / System general attributes

Panopto is video service which offers diverse ways to share videos and create new content in Tampere University. Videos can be shared inside or outside the community and service makes it possible to stream and record events.

Users

Panopto video service can be used by all TAU teachers and students. Video content can be shared publicly, with TAU users or with selected users only.

Content

With Panopto users are able to record and stream lectures using their own laptops or mobile devices. Content can be shared for students via TAU: Moodle. Both live and recorded videos can be created with Panopto. User can also share video content recorded with different services or software by uploading those to the Panopto service.

3.4.4 Kahoot! (TAU)

Platform / System general attributes

Kahoot! is a game-based learning platform that can be used for gamified quizzes.

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Users

Kahoot! is not official teaching tool in TAU, but can be used by teachers. Teacher can share links to quizzes via TAU Moodle or Video-Conference chat-tool. Students can participate to the quizzes with their computers or mobile devices.

Content

Kahoot! is used for activating students within lectures by online quizzes. Quiz result reports can be exported from the system in .xlsx-format.

3.4.5 E-Cla (UNIBO)

E-Cla is a platform used in UNIBO to host language courses and has about 5000 users.

3.4.6 Organizational unit Moodle customizations (in UNIBO)

Further, customized Moodle installations exist in UNIBO to cater for specific courses with specialized needs. These have approximately 5000 users in total.

3.5 Summary table of platforms and systems used by partner universities

Table 1: Education-technological platforms and systems in use at each partner university

System Type	Tallinn University of Technology (TalTech)	Tampere University (TAU)	University of Bologna (UNIBO)
Study information systems	OIS2 (custom built study information system)	SISU (custom built study information system)	SOL - Studenti Online (custom built study information system)
LMS /VLE	TalTech Moodle (customized Moodle installation)	TAU Moodle (customized Moodle installation)	Virtuale (customized Moodle installation)
Other educational systems	KnowledgeHUB (project-specific Moodle installation - this project is led by University of Huddersfield)	EXAM (Electronic Exam Platform)	BOOK (uniBO Open Knowledge) MOOC platform e-CLA (customized Moodle installation) AlmaEsami (Electronic exam platform – only for management purposes) EOL – Esami On Line (customized Moodle Installation for online exams)
Video conferencing	MS Teams Big Blue Button (integrated with TalTech Moodle) WORKSUP (virtual conference platform developed at TalTech) Zoom	MS Teams Zoom	MS Teams Zoom
Other systems	-	Panopto (video sharing) - integrated (plugin) with TAU Moodle Kahoot! (game-based learning platform)	-Panopto (video sharing) – integrated with Virtuale

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3.6 Implications for the proposed BIM-enabled Learning Environment

BIM courses deliver interrelated workflows, including learning materials as well as various types of activities. Platform capabilities (as available in Moodle) enable the application of iframe technology that allow shared models to be integrated into a web browser and this offers possibilities for BIM-enabled learning. Currently, however, no separate or special BIM plugins are currently in use. Integrations are mainly done through shared links to domain specific services (including collaboration workflows where communication/commenting is model-based and accessible by students).

As an open and flexible LMS, Moodle can provide the basic functionality necessary for a BIM-enabled Learning Environment (BLE). It is also a benefit of the Moodle environment that it is very widely used and therefore familiar to most students, teachers and system administrators. The viewing and editing of BIM models could be integrated with a Moodle installation for example, by using iframe technology.

Based on current understanding the most important thing is to make sure that Moodle can be used as a hub for teachers and students that connects different information sources to the same place.

4 BLE Functional Requirements derived from Case Studies

Case studies of existing BIM-enabled learning activities in all 3 partner universities were analysed to determine which functional requirements would be critical / essential / recommended / optional for a BLE. The results of these analyses are presented below.

4.1 TalTech - Description of Learning Experience

4.1.1 Learning Experience Background and Overview

The BIM-enabled Cash Flow Exercise is a learning experience in which students develop, analyse and optimise company cash flows in the context of a construction project scenario. This exercise has been piloted for 2 years (2019 and 2020) within the Construction Investments course at Tallinn University of Technology (TalTech).

Students are typically either fourth year students following an integrated, 5-year Masters of Civil Engineering degree programme or taking a 2-year master's degree having completed their studies to bachelor's degree level previously, in a separate programme. Their industry and BIM experience varies from none at all to a very high level of professional practice. In addition, as the course is one of few in the Construction Management field that is delivered in English at TalTech, it attracts international exchange students who may be from entirely other disciplines.

The exercise involves the project cash flows of 5 companies engaged in a simple car park development construction project. These are a Developer, a Main Contractor and 3 subcontractors (an equipment hire subcontractor, a precast concrete subcontractor and a cast-in-place concrete subcontractor). Groups of students represent each of these companies and their goal is to collaboratively negotiate a global cash flow solution for the project which enables all the companies to meet their (cash flow) objectives.

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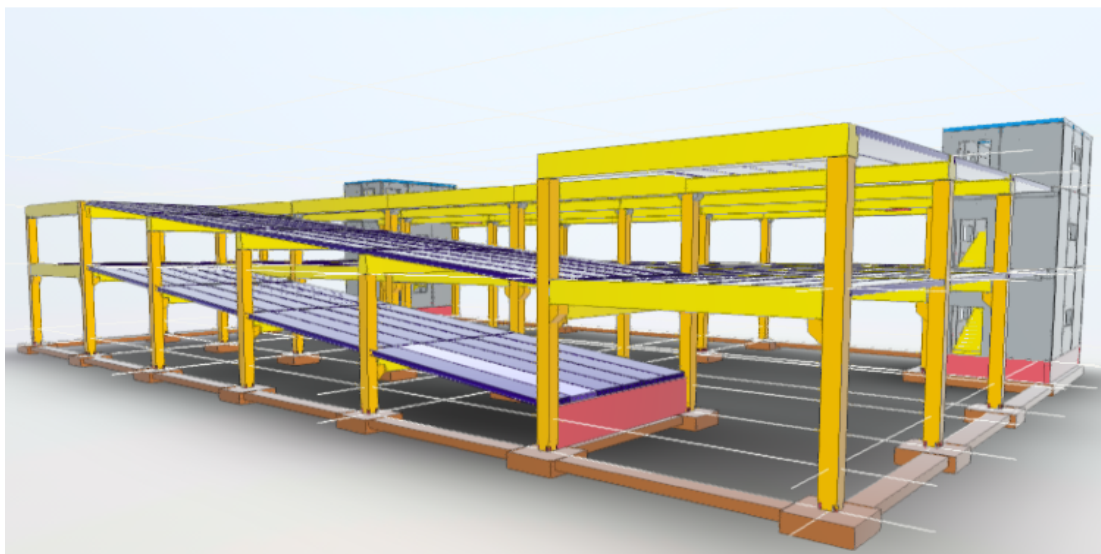


Figure 3: BIM model of the car park development

The project information is provided to students in the form of a '5D' BIM model incorporating both costs associated with all elements of the building and task scheduling of the car park development together with additional financial information (e.g. the maximum cash flow deficits that their companies can accept) and contractual information (e.g. regarding the timings of payments) that influences their company cash flows. The exercise logic proceeds as follows:

1. Students in their company groups develop the project cash flows for each of the companies involved in the car park development project;
2. They then collaboratively negotiate a global solution which enables all the companies to meet their objectives and requirements; and, if this solution requires any changes to the information in the 5D BIM model, then:
3. The necessary revisions are made to the 5D BIM model so that it is elaborated to reflect the outcome of the cash flow analysis and optimisation task (see figure 4 for context).

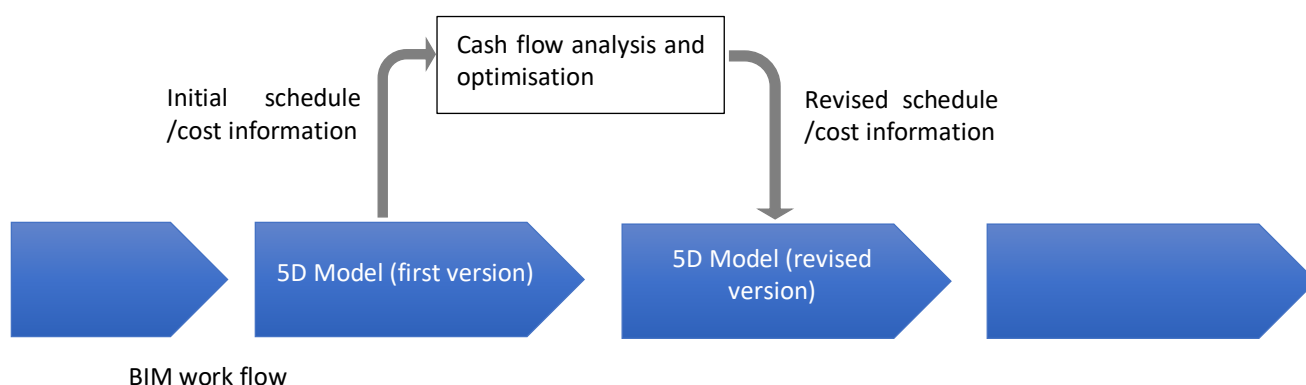


Figure 4: Learning activity in the BIM work flow

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4.1.2 Learning objectives

Students are expected to recall (remember) and understand the cash flow development principles they have learned earlier in the Construction Investments course and to apply these to a realistic construction project scenario (the car park development).

Once the initial cash flows for each company have been developed, students evaluate the impact of different decisions (payment timings, advance payments, etc.) both on their companies' cash flows as well as those of the other companies.

Finally, through a process of negotiation, students use their collective knowledge, experience and ideas in order to create a solution which is mutually beneficial to all the companies involved. In this way, the exercise activates all levels of Bloom's Taxonomy with respect to learning objectives.

4.1.3 Evaluation, feedback and assessment

In its current, pilot format, the focus has been on the reaction of the students to the exercise and a qualitative assessment of whether the exercise has improved their understanding of the importance of cash flows in construction projects. In both cases, this has been very positive. Individual assessment of students' learning has taken the form of students' self-reflection on the exercise and what they have gained from it.

4.2 TalTech - Teaching and Learning Activities involved

4.2.1 Providing / accessing (initial) information

1. Instructor provides instruction documents.
2. Instructor provides 5D BIM model (checked IFC file).
3. Students access and read instruction documents.
4. Students view 5D BIM model.
5. Students view project documents.
6. Students extract cost and schedule data from 5D BIM model (to spreadsheet application).

4.2.2 Developing company (initial) cash flows in groups

1. Students form groups.
2. Students communicate in groups.
3. Student groups are monitored and advised by instructors.
4. Students collaborate in groups with shared viewing of BIM model.
5. Students collaborate in groups with shared viewing of project documents.
6. Students collaborate in groups with shared viewing and editing of spreadsheet application.

4.2.3 Communicating and negotiating between companies (groups)

1. Students communicate between groups.
2. Students collaborate between groups with shared viewing and editing of spreadsheet application.
3. Students collaborate between groups with shared viewing and editing of project documents and project data.

4.2.4 Presenting findings and elaborating / revising the BIM and other project documentation

1. Students edit cost and schedule data in 5D BIM model.
2. Instructors and students check integrity and completeness of revised 5D BIM model.
3. Students present their solution in groups to the instructors and other student groups.

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4.2.5 Reflection, feedback and assessment

1. Instructors create and provide reflection and feedback questionnaires to students.
2. Students access questionnaires, reflect on learning experience (individually and/or in groups) and complete and submit questionnaires.
3. Instructors provide feedback and assessments of students' performance.

4.3 TAU - Description of Learning Experience

4.3.1 Learning Experience Background and Overview

The Simulation of the building design process course has been implemented since 2006 at TAU. For this course the participating students from different disciplines form a design group which consists of the students from architecture, structural engineering, earth and foundation structures, HVAC –engineering, electrical engineering, and construction management and economics. Students' task is designing a building for the predefined need. Each student has a specific role meeting his/her major subject of studies.

The course is implemented through the practice of design meetings, which simulate the actual design meetings. The teachers act as observers and provide feedback. However, the preparations of the meetings and their realizations are entirely on students' responsibility. Between the design meetings, students carry out tasks and arrange smaller meetings according to their roles.

Within this course design work is based on Building Information Modeling (BIM). Produced models are widely used for analyzing the design proposals towards different goals and requirements set by different stakeholders of the building project.

The overall suggestive progress of the course can be seen in figure 5. The progress and the outcomes of the course vary a little every year.

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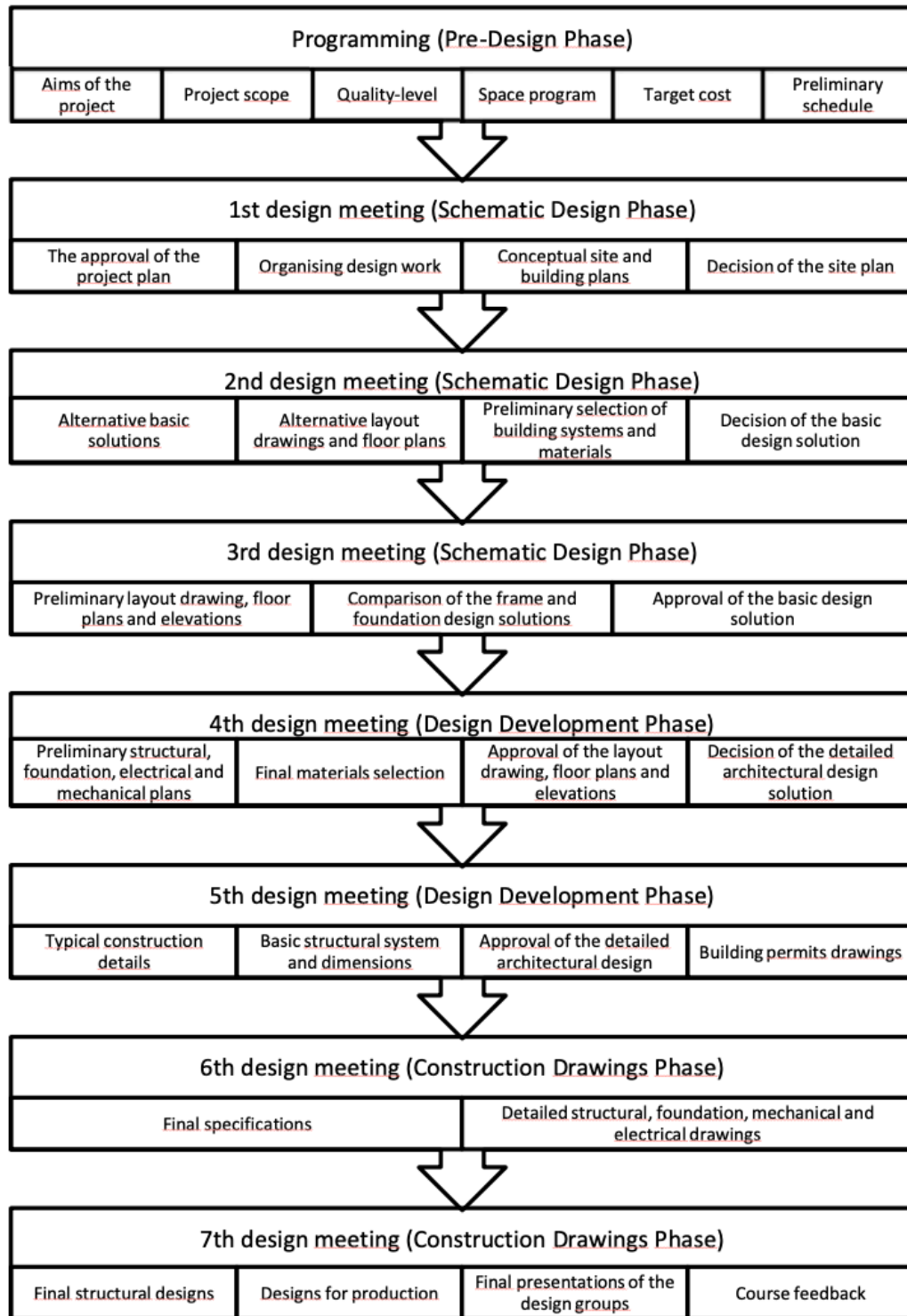


Figure 5: The design process and the suggestive progress of the course

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Figure 6: An example of BIM-based design solution

The course logic proceeds as follows:

1. Students form the requirements for the building according to the provided instruction documents.
2. Students develop design solutions within different design phases towards the requirements. Several aspects need to be analyzed and outcomes should be used for design guidance.
3. Results of each design phase will be presented in design meetings. Also information that is used for decision making should be available.

4.3.2 Learning objectives

Students are expected to understand the design work and collaboration principles they have learned in the course and to apply these to a realistic construction project.

After the completion of the course students are able to work independently as part of the project team. Students understand roles of different disciplines around their own speciality.

Students are able to work in design coordination and technical design meetings efficiently and understand the meaning of negotiation for decision making.

4.3.3 Evaluation, feedback and assessment

In terms of evaluation the focus has been on the reaction of the students to the course and a qualitative assessment of whether the course has improved their understanding of the importance of co-operation in construction projects.

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4.4 TAU - Teaching and Learning Activities involved

4.4.1 Providing / accessing (initial) information

1. Instructor provides instruction documents.
2. Students access and read instruction documents.

4.4.2 Developing design proposals

1. Students form groups.
2. Students communicate in groups.
3. Students forms the specifications for the building.
4. Student groups are monitored and advised by instructors.
5. Students collaborate in groups with shared viewing and editing of BIM model.
6. Students collaborate in groups with shared viewing and editing of project documents.
7. Students collaborate in groups with shared viewing and editing of spreadsheet application.

4.4.3 Communicating with project team

1. Students communicate with project team.
2. Students collaborate between different stakeholders shared viewing of BIM.
3. Students collaborate between different stakeholders shared viewing of project documents.
4. Students collaborate between different stakeholders with shared viewing of spreadsheet application.

4.4.4 Presenting findings and revising the BIM and other project documentation

1. Students provides required changes for the design work (BIM and other documentation).
2. Instructors and students check integrity and completeness of design work (BIM and other documentation).
3. Students present their solution in groups to the instructors.

4.4.5 Reflection, feedback and assessment

1. Instructors create and provide reflection and feedback questionnaires to students.
2. Students access questionnaires, reflect on learning experience and complete and submit questionnaires.
3. Instructors provide feedback and assessments of students' performance.

4.5 UNIBO - Description of Learning Experience

4.5.1 Learning Experience Background and Overview

The BIM-enabled Construction Job Site Layout Exercise is a learning experience in which students develop, analyse and optimise building job site layout in the context of a construction project scenario. This exercise has been piloted for 1 year (2020) within the Construction Management and Building Site Organization course at the University of Bologna (UNIBO).

Students are fifth year students following an integrated, 5-year Masters of Building Engineering - Architecture degree programme. Their industry and BIM experience varies from none at all to a good level of professional practice.

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The exercise involves the construction job site planning of a building project whose architecture design has been developed by the same group of students in the Building Architecture and Technology course of the fourth year.



Figure 7: BIM model of Job site Layout – pedestrian view

The exercise has the aim of providing the fundamental competences needed for the management of a construction project and the design of a construction job site layout.

The project of the construction job site layout aims at minimizing or eliminating hazards for workers that can be found on-site and in-progress:

1. hazards of construction site area and surroundings
2. hazards of process operations portrayed in job site layout

and aims at increasing the efficiency of:

3. production processes and logistics of the construction site

Students will deliver the following job site layout plans, addressing at least one of the following construction stage:

- excavations, foundations and underground floors (mandatory)
- elevation (above-ground works - mandatory)
- roofing (works on the roof of the building) / finishes (interior and finishing works of facades))

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scala 1:1000



Figure 8: BIM model of Job site Layout – aerial view

Job site layout plan will entail the following components:

- temporary works (scaffoldings)
- tower crane and workstations
- logistic and welfare facilities.
- construction site systems (electrical, water) and infrastructures (roads, entrance, etc.)
- site fence

The exercise logic proceeds as follows:

1. Students in their groups develop the job site layout of the building project;
2. They then try to optimize job site layout production-oriented issues considering Occupational Health and Safety needs and constraints and, if this solution requires any changes to the information in the 3D BIM model,

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- then the necessary revisions are made to the 3D BIM model and to the construction logic sequence of activities.

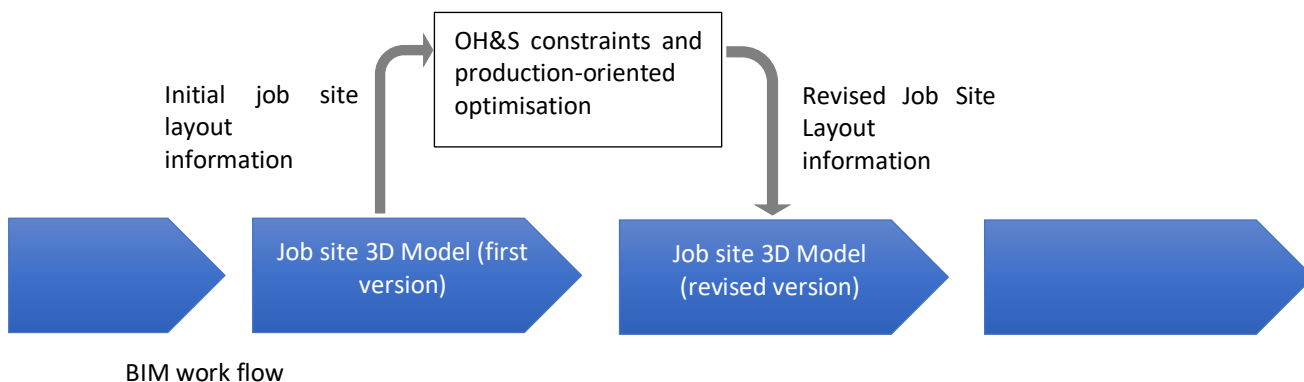


Figure 9: Learning activity in the BIM work flow

4.5.2 Learning objectives

Students are expected to understand the job site layout development principles they are learning in the course and to apply these to a realistic construction project scenario (the building project).

Once the initial job site layout has been developed, students evaluate the impact of different decisions (tower crane siting, site roads and workstations positions, type and structure of scaffoldings) on project stages, operation workflow, and Occupational Health and Safety provisions.

Finally, through a process of optimization, students use their collective knowledge, experience and ideas in order to create a solution which is mutually beneficial to all different production – oriented and OH&S requirements involved. In this way, the exercise activates all levels of Bloom's Taxonomy with respect to learning objectives.

4.5.3 Evaluation, feedback and assessment

In its current, pilot format, the focus has been on the reaction of the students to the exercise and a qualitative assessment of whether the exercise has improved their understanding of the importance of job site planning in construction projects. In both cases, this has been very positive. Individual assessment of students' learning has taken the form of students' self-reflection on the exercise and what they have gained from it.

4.6 UNIBO - Teaching and Learning Activities involved

4.6.1 Providing / accessing (initial) information

- Students form groups.
- Instructor provides instruction documents.
- Students access and read instruction documents.
- Students create a 3D BIM model of building stages
- Students view OH&S and Production – oriented requirements of project documents.
- Students view different type and size of tower crane, safety and welfare facilities, temporary works and workstation locations.

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4.6.2 Developing job site layout (initial) in groups

1. Students choose specific specific locations of site facilities, plants and services, and type and size of tower crane
2. Students develop 3D BIM job site layout initial solution.
3. Students analyse the initial 3D BIM jobsite layout.
4. Student groups are monitored and advised by instructors.
5. Students collaborate with instructors with shared viewing of 3D BIM model.

4.6.3 Optimizing OH&S needs and Production-oriented needs

1. Students identifies OH&S mandatory needs and requirements through 3D BIM model
2. Students identifies production - oriented needs and requirements through 3D BIM model
3. Student find the final solution of 3D BIM job site layout that optimize productivity while fulfilling mandatory OH&S requirements

4.6.4 Presenting findings and elaborating / revising the BIM and other project documentation

1. Students assess and update job site layout data in 3D BIM model.
2. Instructors and students check integrity and completeness of revised 3D BIM model.
3. Students present their solution in groups to the instructors and other student groups.

4.6.5 Reflection, feedback and assessment

1. Instructors create and provide reflection and feedback questionnaires to students.
2. Students access questionnaires, reflect on learning experience (individually and/or in groups) and complete and submit questionnaires.
3. Instructors provide feedback and assessments of students' performance.

4.7 Defined Functional Requirements from all 3 case studies

For all 3 case studies, an iterative process of mapping each of the identified teaching and learning activities involved to specific functional requirements for the BLE followed. This resulted in the initial list of 16 functional requirements shown in Table 2.

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Table 2: Initial list of BLE functional requirements

#	Requirement Description	Importance
1	The upload, storage, download, sharing, viewing of typical file types - documents, spreadsheets, etc.	Critical
2	Collaborative (in groups) viewing and editing of typical file types - documents, spreadsheets, presentation slides, etc.	Essential
3	BIM model viewing, sharing, editing, data extraction.	Critical
4	Collaborative (in groups) viewing and editing of BIM models.	Essential
5	A Common Data Environment for project data (for project-based learning scenarios).	Essential
6	Repository for BIM models and associated project data for learning.	Critical
7	Student group collaboration functionality - group formation, group communications, collaborative viewing and editing of files, whiteboards, etc. Instructor access to groups for advising, monitoring and assessing, instructor options to make changes to groups.	Essential
8	Between groups collaboration functionality - communications between groups, collaborative viewing and editing of files, whiteboards, etc.	Recommended
9	Questionnaire creation, completing, submission, analysis.	Recommended
10	Student feedback functionality.	Essential
11	Assessment / grading functions - grade entering for individuals / groups, grade book.	Critical
12	Collaborative BIM model viewing, sharing.	Critical
13	Collaborative BIM model checking.	Critical
14	Collaborative BIM model editing.	Essential
15	BIM model information take off.	Recommended
16	Project team collaboration functionality - communications with project team, collaborative viewing of files.	Recommended

5 Stakeholder Interviews and Validation of Functional Requirements

5.1 Stakeholder Interviews

Stakeholders were purposively selected in all 3 partner countries according to the relevance criteria that they should be actively engaged with:

- Real Estate and Construction sector training; and/or,
- Real Estate and Construction sector education; and/or,
- BIM-training; and/or,
- BIM-education in any (e.g., academic, industry, etc.) setting irrespective of their mode of delivery in teaching practice.

The selection of interviewees was intentionally directed towards achieving representation from as wide a range of relevant stakeholders as possible. A total of 31 participants (10 from Estonia, 9 from Finland, and 12 from Italy) were interviewed:

- 15 affiliated to Higher Education Institutions
- 14 affiliated to the Construction (AEC) Industry

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- 2 affiliated with the Real Estate / Facilities Management Industry

All interviewees read and signed an informed consent declaration prior to their participation.

A semi-structured interview schedule was used to elicit information regarding the ideal characteristics of a BLE based on the educator's/trainer's lived experiences and aspirations. The interview schedule commenced with an overview of the purpose and context of the research and confirmation of the interviewee's data (name, position, and affiliations). As the interviewees were expected to comment on a concept (the BLE), as opposed to an existing artefact with which they could have direct experience, it was important to establish a common understanding of the general idea of the BLE among all interviewees. For this purpose, a short (1 minute) video outlining the BLE concept with commentary in the local language (Estonian, Finnish, or Italian) was played to them before a series of open-ended questions were asked as follows:

Please describe the teaching/training that you/your organization give (Including subject(s), target audience).

Do you currently use BIM for delivering your teaching/training?

(Alternative if organization only arranges training: Is BIM currently used in the delivery of training arranged by your organization?)

If YES:

How do you use BIM in the delivery? (e.g., for visualizations, project data, communication, etc.)

(Alternative if organization only arranges training: How is BIM used in training delivery?)

If NO:

Could you use BIM to help deliver your teaching/training and for what? (e.g., for visualizations, project data, communication, etc.)

(Alternative if organization only arranges training: Could BIM be used in training delivery?)

Beyond your present area(s) of teaching/training, how do you think BIM could be used in BIM-enabled learning?

(Alternative if organization only arranges training: Beyond the areas of training arranged by your organization, how do you think BIM could be used in BIM-enabled learning?)

What functions would you like to see in a BIM-enabled Learning Environment?

A thematic analysis of their responses, together with the initial functionalities identified from the study of 3 existing BIM-enabled learning activities (described in section 4.7 above), led to the compilation of a list of 30 functional requirements which were subsequently presented for validation at a Stakeholder Workshop.

5.2 Validation at the Stakeholder Workshop

The list of functional requirements was the focus of a (virtual) validation workshop held on 10th June 2021 hosted by Tampere University as part of the first Benedict Multiplier Event at which 26 BIM educators and others interested in BIM-enabled education and training from 5-countries (Estonia, Finland, Italy, Nigeria, Sri Lanka) participated. Workshop participants were asked to validate each of the proposed BLE functional requirements by rating each on their level of importance with a 5-point Likert-type scale (1-Not important, 2-Slightly important, 3-Moderately important, 4-Very important, 5-Critically important). They were also asked to identify any gaps (or missing functions) in the list. A detailed analysis of the interviews, validation workshop and emergent functional requirements are reported in the published journal article: Olowa, et al. (2022). The emerging list of validated functional requirements is shown in Table 3.

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Table 3: BLE Functional Requirements - Validated and Importance Ranked List

Importance		Functional Requirement
Rank	Ave. rating	
1	4,6	Student feedback
2	4,5	BIM model data extraction
2	4,5	Simulation of the project development process (realistic BIM workflow, key stakeholder roles, etc.)
2	4,5	Collaboration in groups
2	4,5	Links between courses (to build on previous courses' results and to track impacts on / inputs to future courses)
2	4,5	Integration of platform with external systems / business
7	4,4	BIM model viewing
7	4,4	BIM model sharing
7	4,4	Common Data Environment (CDE) for project data
7	4,4	Data security / password protection
11	4,3	BIM model collaborative viewing and editing
11	4,3	File upload, storage, download, sharing, editing
13	4,2	Instructor access and monitoring of groups and group work
13	4,2	Hosting of different courses
15	4,1	BIM model checking
16	4,0	Collaborative viewing and editing of documents and spreadsheets
16	4,0	Questionnaire creation, completing, submission, analysis
16	4,0	Video playback
19	3,9	Repository of example BIM models
20	3,8	BIM model editing
20	3,8	Collaboration between groups
20	3,8	Live interactions between users
20	3,8	Gamification support functions
24	3,7	Group formation
24	3,7	Registration of users (learners / instructors)
26	3,6	BIM model creating
27	3,5	Extended reality (XR) functions: AR / MR / VR
27	3,5	Assessment / grading functions - grade entering for individuals / groups, grade book
29	3,4	BIM model version management
30	3,3	Recording of group sessions and lessons
*		BIM object creating and editing
*		Linking to extra learning materials
*		Individual learners' storage for learning materials

* *Suggestions of additional functions received at the validation workshop*

The average ratings received show that even the lowest ranked functional requirement ("Recording of group sessions and lessons") was accorded an average rating higher than "3-Moderately important" and this attests to the general importance and, therefore, validity of the identified functional requirements.

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6 Technical Requirements

Key informants (technical experts in BIM and/or educational technology systems) from each of the partner universities were presented with the list of validated functional requirements and asked to give their recommendations in terms of how these functionalities could be delivered through a BLE. Their recommendations are summarised in Table 4.

Table 4: Potential Technical Solutions with respect to Functional Requirements

Technical Solution Type	Functional Requirements which could be Delivered using this Technical Solution [Square brackets indicate that more than one type of technical solution was suggested]
Learning Management Systems (LMS), e.g. Moodle, with integrated learning tools (using the LTI standard)	Hosting of different courses
	Registration of users (learners / instructors)
	Data security / password protection
	Linking to extra learning materials
	Individual learners' storage for learning materials
	Questionnaire creation, completing, submission, analysis
	Assessment / grading functions - grade entering for individuals / groups, grade book
	Student feedback
	Group formation
	Video playback
	Gamification support functions
	[File upload, storage, download, sharing, editing]
	[Instructor access and monitoring of groups and group work]
	[Collaboration in groups]
	[Collaboration between groups]
	[Live interactions between users]
	[Recording of group sessions and lessons]
[BIM model sharing]	
[Repository of example BIM models]	
Collaboration platforms with integrated applications (e.g. Office 365, Google for Education)	[File upload, storage, download, sharing, editing]
	[Instructor access and monitoring of groups and group work]
	[Collaboration in groups]
	[Collaboration between groups]
	[Live interactions between users]
	[Recording of group sessions and lessons]
	Collaborative viewing and editing of documents and spreadsheets
Integrations with specific BIM solutions	[Common Data Environment (CDE) for project data]
	[BIM model sharing]
	[Repository of example BIM models]
	[Common Data Environment (CDE) for project data]
	BIM model viewing
	BIM model data extraction
	BIM model version management
	BIM model checking
	BIM model editing
	BIM model collaborative viewing and editing
	BIM model creating
	BIM object creation and editing
Extended reality (XR) functions: Augmented Reality (AR) / Mixed Reality (MR) / Virtual Reality (VR)	

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For 3 of the functional requirements, no technical solutions were offered:

- Simulation of the project development process (realistic BIM workflow, key stakeholder roles, etc.);
- Links between courses (to build on previous courses' results and to track impacts on / inputs to future courses);
- Integration of platform with external systems / business.

These functionality options were therefore acknowledged as being potentially useful features but that potential technical solutions for them would need to be considered once they were more clearly defined and understood.

7 BIM-enabled Learning Environment (BLE) design

As shown in Table 3, the identified functional requirements can be separated into 3 general categories:

1. Learning Management System (LMS) functions;
2. Collaboration functions;
3. BIM functions

and these are clearly reflected in the potential technical solutions offered which reference the use of LMS platforms, collaboration platforms, and BIM solutions. Certain functional requirements (e.g. "Collaboration in groups"), could potentially be delivered using more than one of these possibilities.

These findings suggest that the proposed BLE could be achieved on the basis of a host platform that would allow:

- user registrations to be authenticated and managed,
- hosting of course materials,
- assessment, grading and feedback,
- collaboration between learners, between learners and instructors, and between groups.

Depending on individual course needs, further integrations between this platform and specific BIM solutions would extend the capabilities available to the hosted courses. In addition, for a wider, global usership, the possibility of utilizing the eduGAIN system for authenticating and managing users is available. Figure 10 illustrates this conceptualisation of the BLE system design.

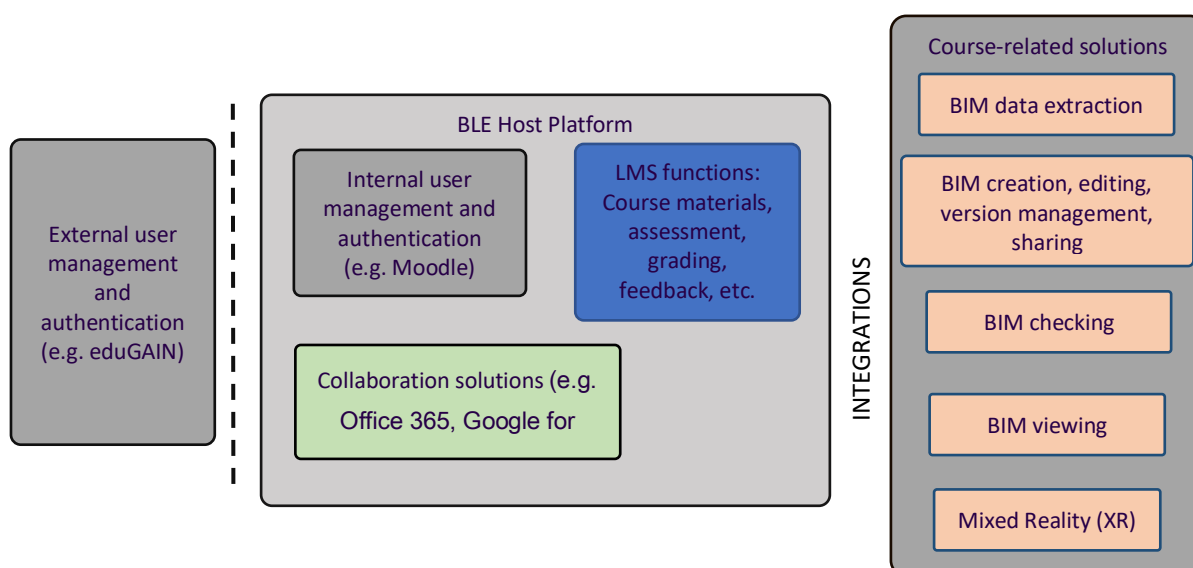


Figure 10: BIM-enabled Learning Environment System Design Concept

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