BIM-enabled Learning Environment (BLE) – System Architecture and its Implementation

By: Tampere University, Finland

August 2023

Co-funded by the Erasmus+ Programme of the European Union

Benedict
BIM-enabled Learning Environment for Digital Construction

Co-funded by the
Erasmus+ Programme
of the European Union

PROJECT DELIVERABLE DETAILS

Project Type	Erasmus+ KA203 Strategic Partnership
Project Acronym	BENEDICT
Grant Agreement Number	2020-1-EE01-KA203-077993
Project Full Title	BIM-enabled Learning Environment for Digital Construction
Intellectual Output	O2 BIM-enabled Learning Environment (BLE)
Output Lead Organisation	TAU – Tampere University
Dissemination level	Final version to be public
Due date for deliverable	1st June 2022

DOCUMENT VERSION HISTORY

Version	Date	Comments
0	20th April 2023	First draft
1	6th September 2023	Complete version for review
2	15th September 2023	Final version for publication

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Executive Summary

The aim of this document is to present the BIM-enabled Learning Environment (BLE) platform and its prototype, designed as a generic and scalable solution for the varying needs of BIM-based education. The developed BLE platform and its prototype are practical enablers for BIM-based educational solutions for vocational schools, high education institutes and professionals' training. The main thinking model behind BLE is to expand all teaching in the Real Estate and Construction (REC) sector to employ the use of digital models. Digital models can provide a revolutionary learning environment where students can learn new skills often along problem-based learning methodology. In practice, this means experiential learning where students are working in a self-directive manner but under systematic tutoring. Learning by doing, group work, peer support and connections to the real world via case project models are characterising further the BLE learning.

The architecture of the BLE platform has been designed to meet needs of different functions (32) that need to be present for such a systemic solution: BIM functions, Collaboration functions and Virtual learning environment functions. These different functions are in a comprehensive manner representing requirements that need to be met with a solution targeting operational use.

Certain, but very limited, software development was completed for the prototype of the BLE platform. The majority of functionalities and capacity of the BLE prototype are based on existing IT technologies. Low cost, vendor independency, maturity/robustness and international use were criteria of importance for the selections of IT solutions for the BLE prototype. Finally, the resultant system takes advantages of various open access software solutions and Open BIM.

The BLE prototype has been applied for planning and implementing the first three pilot courses. These were administered and maintained by the BIM-enabled Learning for Digital Construction (BENEDICT) project partner institutions that led in their development – the Design Management module by Tampere University, the Time Management module by University of Bologna and the Risk Management module by TalTech. The selected technologies and related software proved to be appropriate and value adding. It is possible to build on those for further implementations and widen the use towards other high education institutions, vocational schools and training service providers in the REC sector.

For students and other learners, the BIM-based education needs to be easy to approach, attractive and effective. Proven educational solutions that have broad and scalable capabilities have been selected to be the infrastructure of the BLE platform. It is of importance that the feedback from learners is collected systematically already within the first trials and rounds when BIM-based education solutions are applied. This is the way for understanding learners' experiences and improve those.

With respect to the learning curve for developing solutions of BIM-based education we are in the early stage. The potential of BIM-based education is to be understood step-by-step with implementations for various professional disciplines of the built environment.

1 Introduction

1.1 Background and purpose

Digitalisation is transforming the real estate and construction sector (REC) in a profound manner. The professionals of the sectors, companies, institutions, buildings, and infra-structures together with users are becoming data generators and data users. The physical built environment is to be equipped with digital twins providing mirror representation of physical facilities for the purposes of their monitoring, planning and management.

Along this transformation the education also must adapt. In the big picture, the impacts on education have been rather limited and the potential of digitalised solutions is still largely unrealised. When the companies are often presenting their needs to get skilled people regarding certain software solutions the natural response from educational institutes has been to provide specific education around such tools. These services have been added into the content of existing curriculums without any profound changes to the curriculums themselves.

Clearly, there is a need to reshape the education solutions for the REC sector with digital technologies. The education of different professionals in this sector have naturally already well-established solutions together understanding over different skills and qualifications that are required. But now with digital technologies these skills can be taught and learned in new ways. Whether this is about city planners, architects, structural engineers, construction project managers or HVAC instructors (or any other professionals) the use of digital models can provide a completely new landscape for the education of these professionals.

The purpose of the BIM-enabled Learning Environment (BLE) is to provide starting point for renewing the educational solutions in the REC sector (Witt & Kähkönen, 2019A; Witt & Kähkönen, 2019B). The partners of the BENEDICT project have developed the BLE prototype that is demonstrating the possibilities of new educational solutions.

1.2 Objectives and scope

The main objective for the development of BLE platform prototype is to provide solution that can demonstrate possibilities of digitalisation for renewing the education of the REC professionals. This is a multifaceted challenge where various specific objectives need to be successfully reached. The following summarises those objectives:

- The development of the BLE platform prototype comprises the design, data formats, protocols, functionalities, and IT-solution which constitute a common, open learning environment for the education of various professionals.
- BLE is to act as a repository of learning materials, and which will host the open learning resources (Intellectual Output O3) and pilot modules (Intellectual Output O4) developed as part of the BENEDICT project.
- The resultant BLE platform will be the infrastructure for having a systemic solution for BIM-enabled learning. This refers here to unfolding the possible avenues for education and training where building information modelling (BIM) and its results are utilized in a pervasive manner for the learning benefits of new and existing professionals.
- The BLE platform integrates BIM technologies and their learning with traditional design and engineering studies rather than having separate modules and courses for learning BIM skills.
- Continuing education is of relevance for updating the skills of experienced professionals.

The scope of the BLE solution is broad since it is targeted towards different educational needs. This is addressed via its three educational dimensions of BLE: SPECTRUM, MODES and EXTENT.

The educational **SPECTRUM** presents the various contextual dimensions that are covered by the BLE platform. Those are

1. **Building modelling and production of good quality models** that are useful in different phases of construction projects. This covers different design and engineering disciplines (e.g. architecture and geotechnical, structural and building services engineering). Various BIM analyses, such as visualizations/VR/AR experiments for end users and clients, structural optimization, sustainability and energy efficiency analyses, are in a growing manner an inbuilt feature of modelling itself.

2. **The use of resultant building models** for numerous tasks and needs in construction operations (e.g quantity take-off, cost estimating, scheduling, procurement and supply management).

3. **The interplay and its processes for effective collaboration** between different parties in a BIM intensive construction operation.

The educational **MODES** present the main pedagogical solutions that are present in the BLE platform

1. **Demonstrational teaching** via E-learning and/or Open Course Ware (OCW) lessons. Educational packages for independent studies.

2. **Learning by doing**. Interactive learning according to a systematic study program where instructors and students are linked to each other in a consistent manner for follow-up studies, providing reflections and feedback.

3. **Collaborative learning by project work**. Students are together experiencing a simulated construction project and work in such an environment. This is seen as most advanced educational form where students rather than as a stand-alone excercise can experience the dynamics and complexity of BIM intensive construction projects. These courses can particularly enhance knowledge and competence on project work practices, collaboration with different parties, design meetings, dialogue and problem-solving skills.

The educational **EXTENT** presents the main ways how the BLE platform is entering the built environment profession:

1. **Academic BIM studies**: for different degree programmes (BSc., MSc.) in a single university or for having joint educational courses/modules between universities.

2. **Continuing education**: for universities or other educational and training institutions organising studies on topical matters of interest to professionals.

With its **IT-SOLUTION** the BLE platform provides:

1. **Open learning environment for BIM-enabled education**: solutions are to be open and software vendor independent, and they are to be available for the use of educational and training institutions throughout the Real Estate and Construction (REC) sector. The building models used will be according to open BIM standard and principles; these models shall be available in a standard interoperable format (ifc).

2. **Repository of building models and relating learning resources** (these will be developed as Intellectual Output O3). This includes presentation of educational pilot modules (developed as Intellectual Output O4) and their use.

3. **Available online services** via Internet.

1.3 Methodology of the BLE platform development

The methodology behind the development of BLE platform is design research based on case studies (pilot courses). The resultant development effort can be characterised as an iterative development and learning process (Figure 1). In this process the focus was to understand BLE as an operative educational IT-system and then to implement it as gradually developing BLE generations. A leading principle of importance was to take advantage of existing proven IT-technologies and to avoid large scale technology development. The following presents the main development phases of BLE platform prototype:

BLE Concept and specifications

1. Functional requirements of BLE
2. Technical requirements of BLE

Technical solution

3. Design of pilot courses
4. Functions and solutions for pilot courses
5. Generic BLE solution

Experimenting with BLE

6. Pilot courses (TAU, UNIBO, TALTECH)

The phase 4 included some software development for having certain technical capabilities that were not available. These include scalable virtual reality and browser-based viewing and analysis of models (BIM). Additionally, some specific customising of software packages was completed.

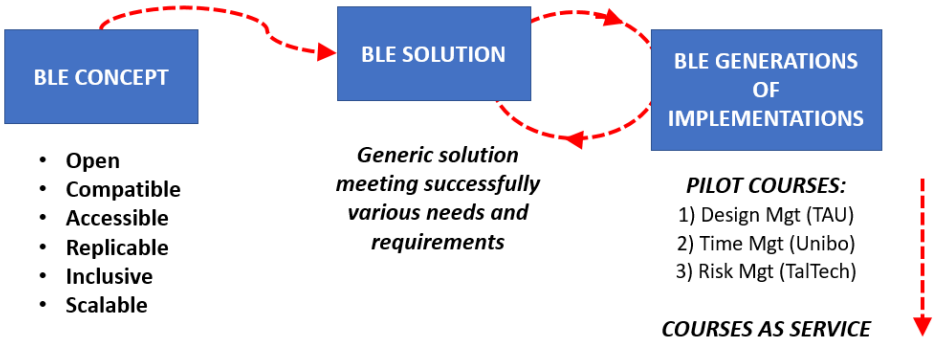

Figure 1: Iterative development of the BLE prototype applying the design research methodology combined with case study.

1.4 Structure of the report

This report is the main BENEDICT document explaining the development of the BLE prototype. The main content of report comprises:

- Introduction to the development of BLE
- Development starting points and principles
- The system architecture
- The BLE platform as an IT-solution
- Discussion
- Conclusions

2 Development starting points and principles

2.1 Significance of BIM technologies for the built environment sector

Digitalisation is changing the REC sector and its services in a radical manner. Digital models of buildings and construction operations (BIM) have a pivotal role here for 1) novel design and engineering practices, 2) interoperability and related data exchange between software tools used by different architectural, engineering and construction professionals, 3) advancing communication and co-operation between different stakeholders in the built environment, 4) life-cycle management from design through to demolition and material circulation. The change is already happening whereas the use of digital solutions is widening, and implications are getting more significant. The resultant benefits are being gradually realised, such as improved productivity, but their overall potential is momentous where the new digital solutions can play a more pervasive role in all sectoral operations. The REC sector-wide education of digital capabilities and skills is a bottle neck.

Digital technologies and their developments are a continuously moving target. During last decade we have realised the appearance of cloud computing, growing significance of AI, maturing of VR/AR/XR technologies and appearance of drones for various data scanning purposes. These are all creating new interesting possibilities for applications in the REC sector. Along with the continuous development of IT we can recognise the lasting significance of BIM technologies. Digital versions of constructions and relating operations provide natural reference points for data access, communication and collaboration. The BIM models act constantly as user-interfaces to required data and its updating. The BIM modelling processes and relating requirements form significant basis for reshaping processes and practices in construction projects.

2.2 BIM enabled learning

The development of BIM education has been conceptualised in three progressive stages (Underwood et al, 2013):

(1) BIM-aware – ensuring that graduates are aware of BIM and the changes it is bringing about;

(2) BIM-focused – students are instructed how to use BIM in the performance of specific tasks; and

(3) BIM-enabled – where learning is embedded in the virtual BIM environment and BIM acts as a “vehicle” for learning.

The final BIM-enabled stage is the one towards which the REC sector needs to target. At the moment, systemic education solution does not exist for this purpose. The “BIM-enabled Learning Environment for Digital Construction” (BENEDICT) project is intended to establish a BIM-enabled Learning Environment (BLE) for advancing digitalisation in the REC sector. This is to be started by developing an ecosystem (BLE platform and content in the form of learning resources and pilot modules) that meets the needs of higher education but, as next step, the system is to expand its services to other types of educational and training needs amongst REC professionals.

INNOVATIVE PRACTICES IN THE DIGITAL ERA FACING THE REC SECTOR: Building Information Modelling (BIM) is needed for realising digital models of buildings and construction operations. The BENEDICT project is aimed at leveraging the emerging possibilities of BIM to enhance the education of construction professionals by developing an innovative BLE which offers opportunities for more immersive and integrated learning experiences. It therefore directly contributes to the development of innovative (educational) practices in this digital era. The resultant BLE will enable learning to take place in the context of real (or near to real) construction project data and will align learning more closely with real (idealised) industry workflows. It will thus support Experiential and Project Based Learning that will take place in an up-to-date, digital environment. Learning within the BLE, students will engage in simulations of industrially relevant tasks and work flows thus ensuring that the skills, knowledge, and attitudes they

acquire are relevant both currently and in the future as the construction industry becomes fully digitalised.

TACKLING SKILLS GAPS AND MISMATCHES: The historical mismatches between single discipline-based higher education delivery and the need for mutual appreciation, understanding, and lacking collaboration between multiple disciplines are predominant in the REC sector. These will be addressed by the BLE where educational solutions are to be built by applying a "learning by projects" approach in which joint learning of different participating disciplines takes place.

PROMOTING INTERNATIONALIZATION: To be widely useful, the BLE must be openly accessible and relatively independent of specific software applications, institutional and national attributes. The BENEDICT project ensures this through developing the BLE collaboratively between institutions in three different countries. By doing so, the BLE will support international collaboration and resource sharing in the field of construction education.

2.3 Functional and technical requirements for BLE (F&T)

Functional and technical requirements of BLE form an important basis for its systemic design. These requirements are based on a questionnaire study and interviews within the BENEDICT partner and associated partner organizations. Thus, the requirements include both academic and industry views over the BLE.

The development of functional requirements produced a rather holistic view of the targeted educational system (Figure 2). The result includes 32 functional requirements that are sorted in three groups: BIM FUNCTIONS, COLLABORATION FUNCTIONS and VIRTUAL LEARNING ENVIRONMENT (VLE) FUNCTIONS. BIM operations of students and instructions have a centric role. This includes requirements for basic operations such as model viewing, editing, and sharing. It is worth noticing that the first functional requirement is about model creation. Basically, this refers to the modelling and use of BIM authoring tools such as Revit, ArchiCAD or Tekla Structures. In the BENEDICT project the focus is not the modelling rather it is on use of models for educational purposes. The model editing has relevance here and for this purpose the limited use of authoring tools may be appropriate as well but their extensive use. The BIM functions also address operations that are taking advantage of technologies such as Extended Reality XR that is understood to include Augmented Reality (AR), Mixed Reality (MR) and Virtual Reality (VR).

The second part of functional requirements is about collaboration between instructors and students, and collaboration between group(s) of students. The leading thinking model here is that these generic functions can serve online, classroom and/or hybrid courses. Additionally pedagogical approaches that are to be applied are highly dependent upon regional educational cultures. Thus, the needs can be very different amongst targets groups arranging their educational services.

The third part of functional requirements (VLE) is about IT support for formal course administration and digital infrastructure for students when they are interacting with course materials, providing their input, and receiving feedback. This includes also certain advanced capabilities (gamification). The openness of BLE as a system towards external world and its resources is characterising this solution (requirements 31 & 32).

The functional requirements were next elaborated with technological viewpoints. This exercise produced the technical requirements of BLE. Each functional requirement was equipped with technical extension characterising its implementation, ranking of requirement and criticality of requirement. For example:

Functional Rquirement	**Rationale** *(needed?)*	**Level of importance (initial interpretation** - *Ranking (by stakeholders)*	*Critical / Essential / Recommended / Optional*	**Related technical requirements**
BIM model viewing	yes	7	Critical	Web platform (integrated or accessible through a shared link) that can read open formats (*.ifc, *.landxml)

BIM FUNCTIONS

1. BIM model creating
2. BIM model viewing
3. BIM model editing
4. BIM model data extraction
5. Repository of example BIM models
6. BIM model sharing
7. BIM model checking
8. Common Data Environment (CDE) for project data
9. BIM model version management
10. Extended reality (XR) functions: Augmented Reality (AR) / Mixed Reality (MR) / Virtual Reality (VR)
11. BIM model collaborative viewing and editing
12. Simulation of the project development process (realistic BIM workflow, key stakeholder roles, etc.)
13. BIM object creation and editing

COLLABORATION FUNCTIONS

14. Collaborative viewing and editing of documents and spreadsheets
15. Group formation
16. Collaboration in groups
17. Collaboration between groups
18. Instructor access and monitoring of groups and group work
19. Live interactions between users
20. Recording of group sessions and lessons

VIRTUAL LEARNING ENVIRONMENT (VLE) FUNCTIONS

21. Registration of users (learners / instructors)
22. Hosting of different courses
23. Links between courses (to build on previous courses' results and to track impacts on / inputs to future courses)
24. Assessment / grading functions - grade entering for individuals / groups, grade book
25. Questionnaire creation, completing, submission, analysis
26. Student feedback
27. File upload, storage, download, sharing, editing
28. Video playback
29. Gamification support functions
30. Data security / password protection
31. Integration of platform with external systems / business
32. Linking to extra learning materials

Figure 2: Functional requirements of BLE

2.4 Creation of BLE

The creation of BLE followed the methodological logic presented in 1.3. The main activities for the development BLE took place in 2022. Important milestones were the BENEDICT meetings and workshops that were arranged in Tampere in November 2021 (online) and January 2022 (Tampere). Directions for development and common understanding amongst BENEDICT partners were valuable achievements of these events. Pragmatic discussions around BLE pilots were also very useful for tackling various practical challenges that are typically faced in this type of education.

Accordingly, the BLE solution was gradually formed and implemented. F&T requirements were used as reference material when decisions were made on certain software solutions and relating arrangements. Additional requirements that were considered are affordability, wide use, user friendliness, and scalability. After selection of main IT infrastructure solutions, the main attention was turned towards course specific needs.

Design of three pilot courses and start of their implementations provided a test bed for the early BLE solutions. These experiments were very helpful for the development of BLE further and to its final form.

3 The system architecture for BLE platform

3.1 The BLE concept

The most important primary concept is BLE itself that stands for BIM-enabled Learning Environment. It is

- Platform for advancing digitalisation in the REC sector. BLE presents the wide use of BIM for different educational needs where digital models can provide learning and skills development infrastructure.
- Addressing various educational institutes (Universities, other high education institutes, vocational education, continuing education, and private training of professionals).
- Platform to enhance the education of Real Estate and Construction (REC) sector professionals
- Offering opportunities for more immersive and integrated learning experiences.
- Including a robust IT-infrastructure
- Providing vendor independent possibilities for course and training

3.2 The structure of BLE platform

The top-level structuring of the BLE platform has been designed to satisfy successfully various F&T requirements and additional requirements that were identified during the creation of BLE. The main elements of BLE platform are (Figure 3)

1. Hosting frame for different course implementations:
    - Course management system (CMS): documentation, tracking, reporting, automation, and delivery of courses
    - Interactive group working solutions:
    - Repository for course materials: digital models and their specifications, course descriptions and relating supporting documents and materials
2. Course related solutions:
    - *Interaction with models (BIM):* tools for basic BIM operations such as BIM viewing and data extraction, these have been identified as commonly existing needs for various educational purposes
    - *Professions specific tools*: data operations are dependable upon the characteristics and practices of different professions. Principles of Open BIM are here providing possibilities for the inclusion of such tools.
3. User management and authentication:
    - Institutional solutions for formal administration of students (registrations, authentication, authorisation, awarding course certificate/diploma)

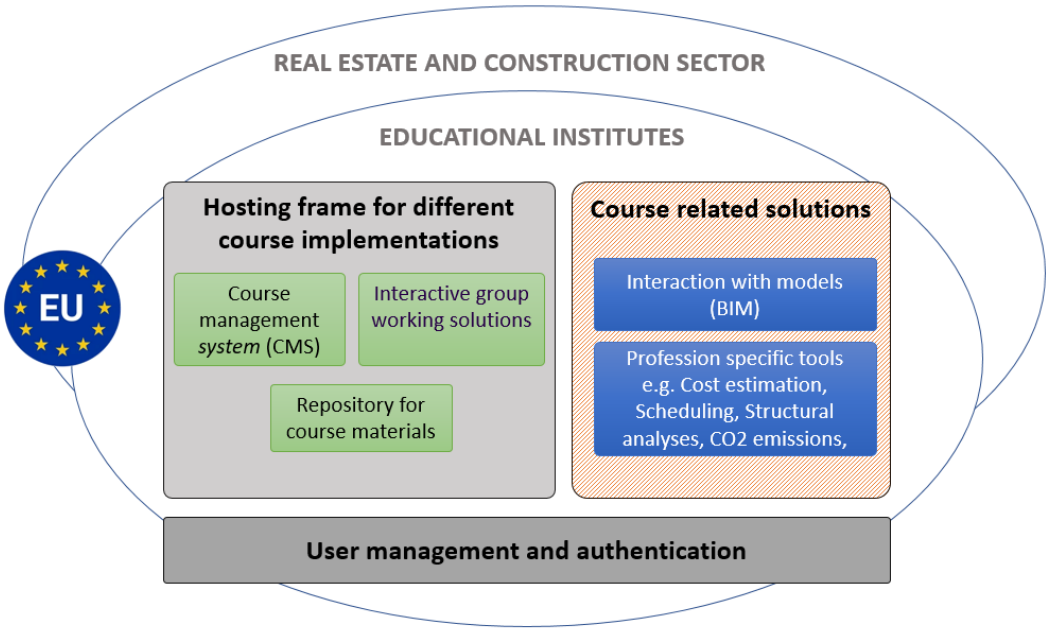

Figure 3: The top-level structure of BLE platform.

3.3 The utility of BLE platform

Creation of possibilities for exploitation is one of the requirements that was considered thoroughly where the BLE platform structuring, and later its IT solution was developed:

- *Educational platform for the REC sector*: Generic solution for renewing educational services in a sector-wide manner. This to meet different professions in the REC sector.
- *Scalability*: number of students, duration of teaching modules/courses, content (models, supporting materials), generally scalability is only limited by the used IT infrastructure (HW & SW)
- *Openness towards different pedagogical approaches*: BLE is not build around any specific pedagogical approach.
- *Various educational institutes*: From vocational schools to universities. Continuing education as a special case where private course organisers and training companies can be service providers.
- *Regional independency*: educational organizers and service providers can locate in different regions and countries.

4 The BLE platform as an IT-solution

4.1 The IT architecture

The main principles for the IT architecture of BLE has been presented in 2.4. Here the vendor independency and

affordability resulted in the use of open-source software solutions in an extensive manner. Additionally, it is worth mentioning that relying on the use of ifcs the BLE is operating according to openBIM (Figure 4).

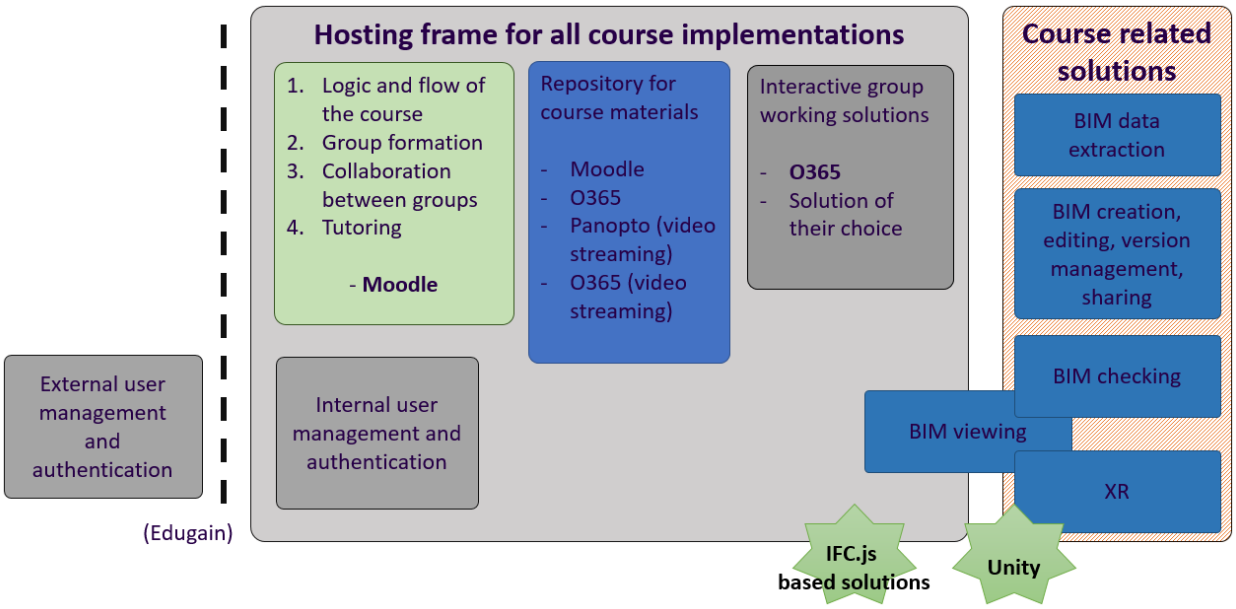

Figure 4: The IT architecture of BLE platform

4.2 Platform and Course administration solutions

The first three pilot courses that have been developed with the purpose of demonstrating the BLE have each been administered and maintained by the partner institution that led in their development – the Design Management module by Tampere University, the Time Management module by University of Bologna and the Risk Management module by TalTech. Course-level administration by each institution includes course enrolment policies and setup, content control, managing assessment and grading, etc. It is envisaged that future courses would, similar be administered by their developers under the auspices of higher-level, BLE platform administration. In the case of the current, demonstration BLE platform, this higher-level administration – management of authentication, user accounts, registration, roles and permissions, etc. is being carried out by TalTech in its role as project coordinating institution.

4.3 Hosting frame for all course implementations

A project-specific Moodle installation (currently version 3.11) on a web-server with the address https://www.bim-enabled-learning.com provides the hosting frame for all course implementations. This arrangement was adopted in preference to making use of our existing, partner institutional Moodle servers as it allows full, common access to a single BLE platform by all project partners and, potentially, any users from the global public without requiring pre-registration with any host institution or organisation.

The choice of Moodle as a hosting frame, which, during the BLE specification research, was identified as a common Learning Management System (LMS) currently used in all BENEDICT partner institutions, ensured that all partner institutional staff (and many teachers and trainers beyond the partner institutions) already have a working knowledge of the basic platform.

4.4 Course specific solutions

4.4.1 BIM operations

During the specification phase of the project, the project team identified BIM viewing and BIM data extraction as two mandatory functions of the BLE system. To ensure interoperability and collaboration in the system, the team determined that the system would rely on open BIM standards.

To identify an open source solution that could meet the project's needs, the team conducted an evaluation of various options. After consideration, the IFC.js framework was deemed the most suitable for the project and, as part of the BLE development activities, a Moodle plugin has been developed under the Benedict project that integrates a high performance IFC.js-based application with the BLE. This plugin is available for any organisation to utilize with their Moodle installation in order to open, view and extract data from IFC files.

The utilization of the IFC.js framework in the BLE system involves integrating it into the project, loading IFC data, visualizing the data in a 3D viewer, querying and filtering the data, and extracting the data from the BIM model. This enables the system to fulfill the mandatory functions of BIM viewing and BIM data extraction.

By incorporating the IFC.js framework into the BLE system, the users can leverage its capabilities for loading and visualizing BIM data in a 3D viewer. Additionally, the framework's querying and filtering functions can assist with extracting specific data from the BIM model, which is essential for fulfilling the

With this open source solution BLE can be used both in commercial and non-commercial purposes. This gives great opportunity also for industry users for BIM enabled education.

4.4.2 XR technologies

Extended virtual reality environments (XR) are providing environments for the advanced use of digital building models. XR enables communicative sharing of building models and relating details towards different disciplines and parties. It is of importance to provide understanding of these possibilities to students. For this purpose, the possibilities to include XR to the BIM Enabled Learning Environment were explored. This specific task was led by Tampere University and certain specific software and hardware expertise of significance ware provided by Mr. Daniel Leggat / Alter - Experience Ideas Ltd.

A visualisation in an XR environment is a specific use case with certain timing (phase of construction project), objectives, requirements and users. Definition of XR use case provides the basis for importing of a standard BIM model to an VR/XR environment. This importing task includes alterations, editing or even re-modelling. This pipeline and needed effort within have been studied for understanding the required process. The resultant XR model is a cheerleading training centre. This building has been modelled by architecture, structural engineering and construction management students of Tampere University (Figure 5). The developed XR model represents a scalable solution that can be used by different software and hardware solutions starting from a web browser up to state-of-the-art XR studios:

Walk through video (standard browser)
Walk through video with stops for interactive viewing (3DoF, standard browser)
Fully interactive experimenting of the building on computer screen (3DoF, specific Unity based app)
Fully immersive experimenting of the building in XR studio (6DoF, Varjo Headsets with relevant XR studio hardware)

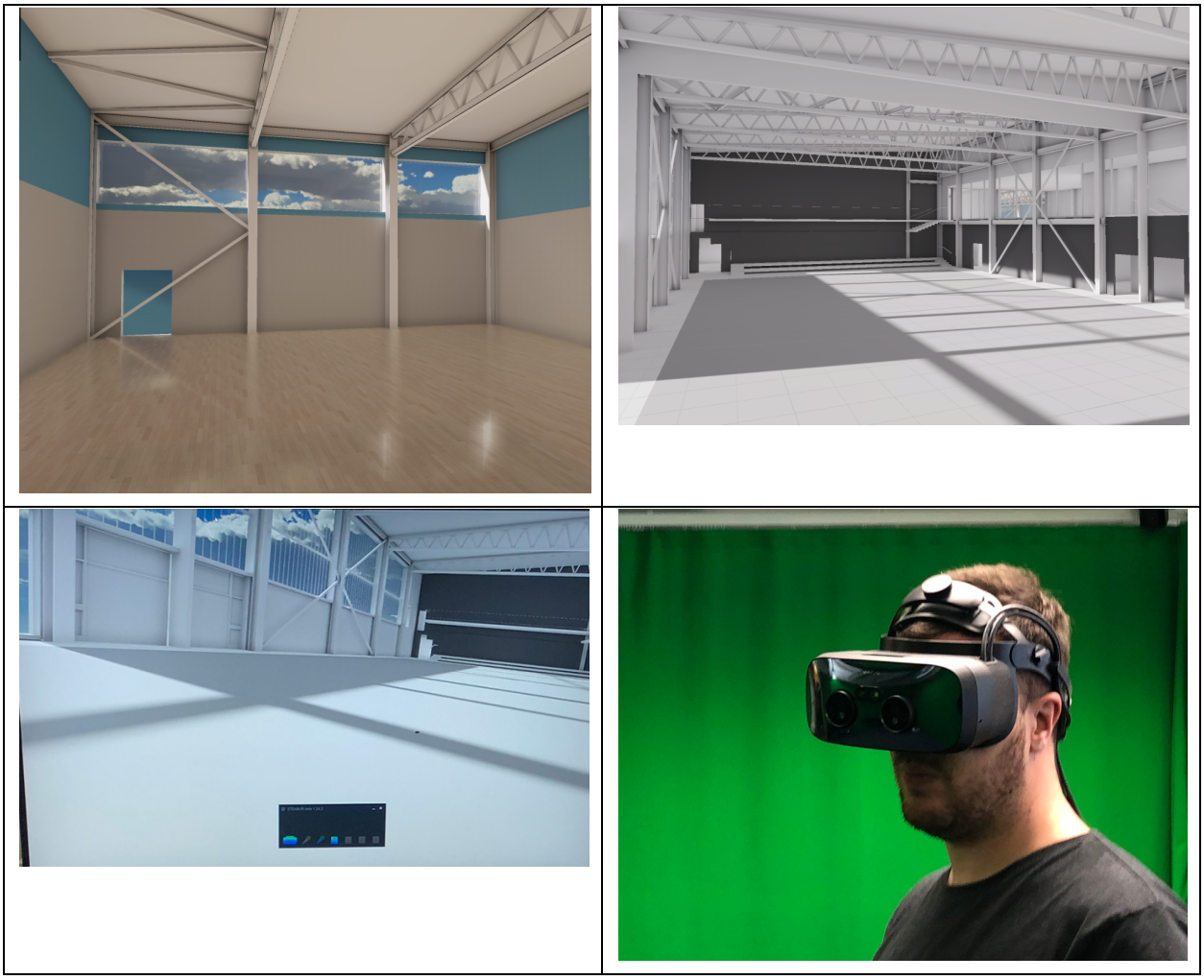

Figure 5. XR-solution demonstration for the BLE platform.

4.5 Open Learning Resources repository

The BLE relies on a repository of learning resources to support its courses. These resources take the form of sets of real (or near real) project data including descriptions of projects, technical BIM models that have been checked for representing the appropriate data formats and for containing suitably consistent data at the desired level of detail, project plans linked to the technical building models (quantity take offs, schedules, cost estimates, resourcing, procurement of materials, components and other supplies). It is essential that the resources within this repository are organised / classified in a user-friendly way so as to promote their widespread use and incentivise the development of high quality BIM-enabled learning resources.

Open learning resources or Open Educational Resources (OER) are learning, teaching and research materials in any format and medium that reside in the public domain or are under copyright that have been released under an open license, that permit no-cost access, re-use, re-purpose, adaptation and redistribution by others (UNESCO, What are Open Educational Resources?). Open educational resources (OER) are freely accessible, openly licensed instructional materials such as text, media, and other digital assets that are useful for teaching, learning, and assessing, as well as for research purposes. The term "OER" describes publicly accessible materials and resources for any user to use, re-

mix, improve, and redistribute under some licenses. These are designed to reduce accessibility barriers by implementing best practices in teaching and to be adapted for local unique contexts. (Wikipedia Open Educational Resources).

In the specific case of construction management – oriented applications, Open Learning Resources will be supplied to students and applicants as actual case studies. Each case study consists in one or more than one building or civil engineering facility that has been designed and engineered in previous courses of the university programme, or provided by the associated partners. The output of the students' work, indeed, need to be stored in the repository.

A categorization of OLR by file format is presented in the following table.

OLR	Examples	File format
Descriptions of projects	project objectives; site description and analysis; media concerning the site; building overall concept description; statement of work (SOW); building systems reports, drawings and calculation	.docx; .xlsx; .pdf; .dwg; dxf; xml; mp4; JPG
Technical BIM models	BIM objects; BIM model	.ifc
Project Plans	architecture and envelope layout; structure layout; MEP systems layout, construction process. bills of quantities; budgets; schedules; resource estimation, procurement documentation concerning materials, products, components and other supplies; safety plans	docx; .xlsx; .pdf; .dwg; dxf; xml; mp4; JPG

Table 1. OLR categorization

As an example, the following documentation (output) can be produced by the students of construction engineering and management with Building Information Modeling.

- Project Planning, job site design & safety planning i.e. 4D BIM including:
  - Work Breakdown Structure.
  - Construction project schedule
  - Construction site design

The BLE has a Pilot Module Section, that includes documentation and content of each specific pilot module course, and a Repository Section, that includes Learning Resources. BLE users are teachers, learners and system administrators.

The OLR repository is hosted by the University of Bologna, via a Content Manager System (CMS) linked to the BLE. The CMS has the function of searching OLR in the repository according to a classification system. The repository architecture is presented in figure 6.

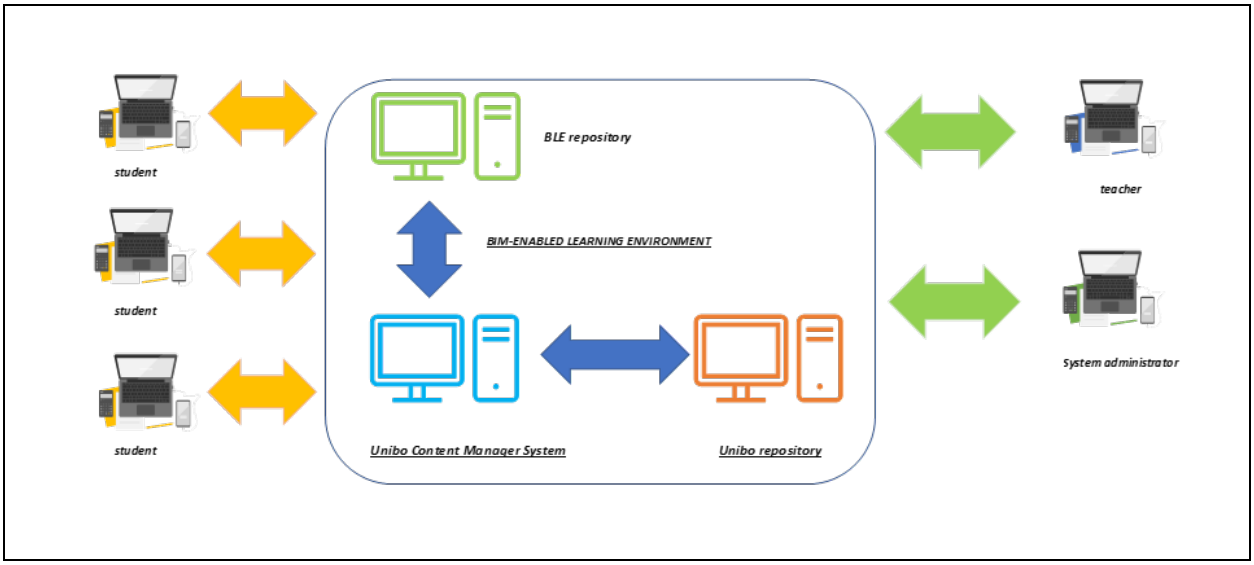

Figure 6. BLE Repository Architecture.

4.6 System maintenance

The demonstration version of the BLE is partly hosted by all the Benedict partner institutions – TalTech hosts the BLE Moodle platform, the Open Learning Resources repository is hosted by the University of Bologna and the XR materials by Tampere University. Thus, system maintenance for this dispersed demonstration BLE will be dealt with by the individual hosting institutions. For the BLE Moodle installation, this entails ensuring that the host web-server continues to have suitable memory capacity to enable the smooth running of the BLE, continuously updating software and checking that plugins, etc. are fully functional, and controlling / maintaining user authentication services. In terms of the Open Learning Resources repository, the University of Bologna will ensure that sufficient server space is provided to cope with the learning resource files and their use in courses as well as curating the resources (data sets) themselves. Tampere University will maintain the XR related materials which they host.

5 Discussion

BLE platform and its prototype are concrete enablers for BIM based educational solutions for vocational schools, high education institutes and professionals' training. The main thinking model behind BLE is to expand all teaching in the REC sector to employ the use of digital models. Digital models can provide a revolutionary learning environment where students can learn new skills often along problem-based learning methodology. In practice this means experimental learning where students are working in a self-directive manner but under systematic tutoring. Learning by doing, group work, peer support and connections to the real world via case project models are characterising further the BLE learning.

In the Benedict project the BLE prototype was applied for planning and implementing the first three pilot courses. These were administered and maintained by the partner institution that led in their development – the Design Management module by Tampere University, the Time Management module by University of Bologna and the Risk

Management module by TalTech.

The architecture of the BLE platform has been designed to meet needs of different functions (32) that need to be present for such a systemic solution: BIM functions, Collaboration functions and Virtual learning environment functions. These different functions are in a comprehensive manner representing requirements that need to be met with a solution targeting operational use.

Certain, but very limited, software development was completed for the prototype of BLE platform. Majority of functionalities and capacity of the BLE prototype are based on existing IT technologies. Low cost, vendor independency, maturity/robustness and international use were criteria of importance for the selections of IT solutions for the BLE prototype. Finally, the resultant system takes advantages of various open access software solutions and Open BIM.

User viewpoints are always of importance when any software applications are developed. With BIM enabled learning the developers need to take account variety of users such as teachers and different learners (students, professionals). For teachers and for the institutions they are representing is first of importance to offer solutions such as Open Learning Resources repository. This repository provides starting points and materials for the new course development. Hosting frame for course implementations provides solutions for setting up and running course practicalities.

For students and other learners the BIM based education needs to be easy to approach, attractive and effective. The proven educational solutions that have broad and scalable capabilities have been selected to be the infrastructure of BLE platform. It is of importance that the feedback from learners is collected systematically already within the first trials and rounds when BIM based education solutions are applied. This is the way for understanding learners' experiences and improve those.

6 Conclusions

The BIM based education solution enabled by BLE platform and its prototype is designed to be generic and scalable for varying needs. It has been tested for implementation of three trial courses in University of Bologna, in Tallin University of Technology and in Tampere University. The selected technologies and relating software proved to be appropriate and value adding. It is possible to build on those for further implementations and widen the use towards other high education institutions, vocational schools and training service providers in built environment sector.

With respect of the learning curve for developing solutions of BIM based education we are in the early stage. The potential of BIM based education are to be inside out understood step-by-step with implementations for various professional disciplines of the built environment.

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