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ON-LINE REPOSITORY OF DIGITAL RESOURCES FOR A BIM-ENABLED LEARNING ENVIRONMENT

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SUMMARY: *In the field of Architecture Engineering and Construction (AEC), Building Information Modelling (BIM) has increasingly assumed an important role, especially for construction simulation. BIM is needed for various building and management systems, particularly for project construction management. Students, teachers and operators of AEC need to have access to the data, reports and information that allow the creation and use of BIM models. "BENEDICT" is an EU Erasmus+ project that has the aim of developing a web-based platform for BIM-enabled learning associated with the AEC industry. A BIM-enabled Learning Environment (BLE) can be used to implement BIM-based project planning and control system for learners and future practitioners, with Open Learning Resources. Open Learning Resources (OLR) are learning, teaching and research materials in any format and medium that are useful for teaching, learning, and assessing as well as for research purposes. In addition to the BLE platform, a BIM-model repository was developed to store information, OLR and students' outputs for each component of the project and of the project-related learning activities. The BLE and integrated OLR repository help students, teachers and practitioners to implement BIM with actual project models by developing an on-line repository of digital models, objects and elements, therefore enabling knowledge transfer between different stakeholders.*

KEYWORDS *Building Information Modelling, Open Learning Resources, Learning Environment, Construction.*

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1. INTRODUCTION

The construction industry is one of the largest in the world economy, with about $10 trillion spent every year for construction related goods and services. However, construction productivity has lagged behind that of other industrial sectors, such as manufacturing and retail, that have implemented digitization and innovation, increasing their productivity over time. This productivity gap has many causes, and Building Information Modelling (BIM) is considered one fundamental strategy to recover the desired level of performance (European Construction Sector Observatory, 2021). BIM involves the use of a shared digital representation of a built object to facilitate design, construction and operation processes to form a reliable basis for decisions (ISO 294811:2016). A built object can be a building, a road, a bridge, a process plant, or anything that belongs to the built environment. A building construction information model is a shared digital representation of physical and functional characteristics of a built object (ISO TS 12911), therefore the term modelling addresses the process of managing information related to the facilities and project in order to coordinate multiple inputs and outputs, regardless of the specific implementation. BIM is a method or strategy, not a tool. In the construction sector, knowledge transfer between different stakeholders - owners, designers, construction specialists, and project operators, together with project procurement take place by data exchange, i.e. information exchange. Among the specific features of the BIM methodology is the ability to store information for each individual component of the project, including three dimensional properties and data concerning materials, building products, structure, quality performances, construction operations, transformation or installation stages, maintenance, time and cost data, sustainability and health and safety related information. Therefore, the fundamental element of this method is a digital model capable of n-dimensional representation of a building. BIM is considered a powerful approach to improve productivity in the Architecture, Engineering and Construction (AEC) sector. The use of BIM is spreading rapidly in many countries, covering a wide range of projects both in the public and private sectors. Digitization of the construction sector involves the need to help both students and practitioners to implement BIM with actual project models by developing an on-line repository of digital models, objects and elements. Particularly focusing on educational processes, there is a strong need to develop a shared, online repository of BIM models to provide an effective and coherent basis for BIM project implementation (Becerik-Gerber, 2012, Boeykens et al. , 2013, Clevenger et al. 2013, Puolitaival, Forsythe, 2016). The BIM-Enabled Learning Environment for Digital Construction (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). The BENEDICT project deals with how to teach courses at university level with BIM tools, in particular through the use of an IT platform comprising a BIM-enabled Learning Environment (BLE) and an Open Learning Resources (OLR) repository for BIM models (Olowa et al. 2022; Ruutman et al., 2022; Witt, Kahkonen, 2019).

The fundamental needs of Architects, Engineers, Construction Managers, and students of these disciplines concerning BIM involve the design, development and implementation of various building and management systems, for instance:

- Architectural systems and space coordination: i.e architectural layout and spatial units (size and coordination, proximity relationships, internal partitions);
- Structural systems: i.e. foundations, columns, structural slabs and basement structures, superstructure, reinforced concrete framework, GLT and solid timber frame, CLT and prefabricated panels, floors and roof structures;
- Enclosure systems: i.e. architectural language and facades, doors and windows, architectural finishes, waterproofing, roofing;
- Mechanical /Electrical / Plumbing - MEP systems: i.e. connection systems, elevators, mobile staircases;
- Construction project systems: i.e. construction site provisions and equipment (e.g. scaffolding systems, tower cranes, formwork, etc.);
- Project Construction Management systems: i.e. project control methods and tools concerning project description, integration and implementation, project planning and time management, project risk management, project cost, quality and resources management.

The needs of BIM-enabled Learning Environment (BLE) users – learners, teachers, system administrators – include having the availability of data, reports, and information concerning architecture and engineering systems. The technical data and information concerning design, development and installation of the building and its project management activities allows BLE users to create the BIM model. For example, construction management students will need a set of case studies to be tested with practical exercises and the OLR will be supplied as actual case studies - each case study consisting of a building or facility that has been designed and engineered in industry or in previous courses. Learning experiences using these will greatly enhance BIM-enabled learning where BIM-based workflows will provide immersive learning and training opportunities. BIM–enabled learning can use a virtual platform, a web site and OLR repository, where all BIM models, examples and data can be stored and used. The BLE provides the learning environment specifically designed to support this type of learning. Key resources for the use of the BLE are available from an integrated OLR repository.

The purpose of this research is to develop and demonstrate a practical prototype of a BLE and integrated OLR repository for use in AEC education which will serve as an example for others who are encouraged to replicate and further develop such learning environments. The requirements definition, conceptualization and development of the OLR are specifically focused on in this research. In the next section of this article, the relevant literature is first reviewed and the BENEDICT project presented. The research methods are then explained before the findings – a detailed description of the development of both the BLE and the OLR – are presented. A brief discussion of how the BLE and OLR were received in their use in teaching pilot modules is followed by conclusions.

2. LITERATURE REVIEW

2.1 AEC Education Evolution

The history of engineering education is intertwined with physics, chemistry, mathematics and many other sciences, and therefore relates back to ancient times (El-Sayed & El-Kilany, 2019). The roots of formal engineering education are in France, where the École des Ponts et Chaussées was established in 1747, and these laid the foundation for formal civil engineering education (Aparicio & Ruiz-Teran, 2007). Academic architecture education has its origins in the late 1600s, also in France, where the Académie d'Architecture was established in 1671 (Griffin, 2019). Architecture and engineering co-existed for a long time in academic education, but eventually split up, with architecture focusing on art and engineering on science. While the history of architecture and engineering education is relatively long, construction management as a taught subject has existed only from the 1950s (Arditi & Polat, 2010). Construction management education was built upon the fundamentals of civil engineering education, however, the disciplines started gradually evolving separately, leading to undergraduate and graduate programmes specifically dedicated to construction management. Construction projects have become increasingly complex to carry out and the professional practice of the disciplines has become ever more specialized and fragmented. Education has mirrored this fragmentation by separating the three (Architecture, Engineering and Construction) disciplines (Mathews, 2015). Although the separation has been important to address the complex needs of the modern AEC industry, there are also some drawbacks in this development. One of the major drawbacks of these disciplinary silos are reflected in the adversarial relationships between specialists from these different areas in projects instead of collaboration and cooperation.

When traditionally architectural or engineering knowledge was enough for the graduates to start working, in the late 1980s demands for the graduates started changing. Graduates were required to obtain not only traditional architectural or engineering competences, but also communication, teamwork, creativity, innovative and critical thinking skills (Arditi & Polat 2010). To address the development of these skills, student-centred learning methods started emerging introducing project-, problem- and case-based methods, although it can be argued that these elements have always existed in some form within AEC education (Arditi & Polat 2010). Student-centred learning methods are gradually replacing or have already replaced the traditional behaviouristic methods in AEC education (Puolitaival & Kestle 2018).

2.2 BIM Education

In the early 2000s, BIM and BIM education started to gain momentum in the research literature (Puolitaival & Kestle 2018). To support BIM competency development, a good number of competency frameworks have been created for education and training, and also for organisations' self-evaluation. Succar (2013) introduced one of the first BIM competency frameworks in 2013. His model was created to assist organisational BIM capability development by offering a framework and a tool to measure BIM maturity at the organisational level. Work has been done at the national level such as the BIM Academic Forum (BAF) framework in the UK for BIM learning outcomes, in various BIM-related organisations such as buildingSMART and in numerous educational organisations and private training organisations across the world (Puolitaival & Forsythe 2016). Curriculum development has been another popular research area. Barison and Santos' (2010) work was one of the first reviews on BIM curriculum, Sacks and Pikas (2013) and Pikas et al. (2013) published a two-part article on BIM education for construction engineering and management. The first part focused on industry requirements, state of the art and gap analysis, and the second one on procedures and implementation case study. Abdirad and Dossick (2016) focused on BIM curriculum design in AEC education. More detailed research on BIM education followed introducing teaching and learning approaches and methods. BIM has been taught as a standalone topic and also as an embedded component in existing AEC courses. Project-based learning as a learning method has been used widely in BIM education (Becerik-Gerber et al. 2012, del Savio et al. 2023, Puolitaival & Kestle 2018, Udeaja & Aziz 2015, Wu & Luo 2016). The nature of BIM as a virtual project environment (Becerik-Gerber et al. 2012, Brewer et al. 2015) has enabled to lift project-based and other student-centered learning methods to a whole new level.

BIM has been seen as an approach to improve productivity of the AEC sector (European Construction Sector Observatory, 2021). It enables and also requires collaboration and cooperation between the disciplines, breaking up the silo mentality in projects (Poirier et al. 2017). Also in education collaborative and multidisciplinary learning has been popular over time (MacDonald and Mills 2011, Pikas et al. 2013, Plume and Mitchell 2007, Shelbourn et al. 2016, Udeaja & Aziz 2015).

BIM education faces similar challenges as education in general and the lack of educational resources has been recognised by many (Becerik-Gerber et al. 2011, Gier 2015, Puolitaival & Forsythe 2016). Puolitaival and Forsythe (2016) highlighted the shortage of appropriate models as one of the key challenges. There are various ways to obtain models, all come with their own challenges. Obtaining models from the industry has two key issues: intellectual property issues and model complexity (Puolitaival & Forsythe 2016). Authoring models purely for educational purposes is resource consuming while collaboration and open sharing of resources is needed for the wider offering of BIM education.

2.3 BIM-Enabled Education

The concept of “BIM-enabled” education was proposed by Underwood et al. (2013) as the culmination of progressive stages in the development of BIM education through:

1. BIM-aware education ensuring that graduates are cognizant of BIM and the changes in industry that it is bringing about;
2. BIM-focused education, in which students are taught to use BIM for specific tasks; and then,
3. BIM-enabled education where learning is embedded in a virtual BIM environment so that BIM acts as the medium or vehicle for education. (Underwood et al., 2013)

This reflects the broader notion of BIM bringing about a transition from traditional professional and educational practices that divide projects and teaching between specialist areas, towards the integration of work and information flows for whole projects and, in parallel, multidisciplinary and integrated learning approaches (Forgues and Becerik-Gerber, 2013). Similarly, a change from an approach based on abstraction and towards simulation with the use of virtual building models (Ambrose, 2012).

In their investigation of extant examples of BIM-enabled education, Witt and Kähkönen (2019a) categorised reported cases in the academic literature into two general groups:

1. Where traditional learning processes were enhanced through the deployment of some aspect(s) of BIM - i.e. BIM being used as a learning tool; and
2. Where learning took place within a BIM context in the sense of BIM providing a common platform for information transfer and / or where BIM workflow processes were adopted - i.e. BIM as a learning environment. (Witt & Kähkönen, 2019a).

Boeykins et al. (2013) considered BIM to represent an educational methodology in itself that students can directly experience, while Zamora-Polo et al. (2019) argued that, for the education of engineers, BIM can be considered a Virtual Learning Environment (VLE). However, to facilitate effective BIM-enabled education in practice, Witt and Kähkönen (2019b) identified the need for a purpose-built BIM-enabled learning environment and proposed a general, conceptualization of one.

2.4 Virtual environments to support BIM-Enabled learning (BLE) & benedict project

The concept and utility of learning environments are reflected in the writings of the pragmatist philosopher and educational reformer John Dewey who noted that environment is essential to education – "We never educate directly, but indirectly by means of the environment" - and that the educational environment may be a chance environment, as appearing in everyday life, or an environment specially created and deliberately regulated for its educational effect on learners. In addition, since education is an active and constructive process, the educational environment must be equipped with the necessary agencies, tools and materials for doing (Dewey, 1916). Similarly, Kolb's Experiential Learning Theory (Kolb, 1984) embraces the importance of environment to learning and introduces the concept of "Learning Space" which elaborates the transactions between learner and environment. Learning Spaces include creating a hospitable space for learning; making space for conversational learning, development of expertise, acting and reflecting, feeling and thinking, linking educational experiences to the learner's interests, and, learners taking charge of their own learning (Kolb & Kolb, 2005).

Various attempts at the creation of bespoke BIM-enabled Learning Environments (BLEs) of different types have been experimented with in the past. For example, Ku and Mahabaleshwarkar (2011) proposed a platform combining the Second Life virtual environment with BIM to create a web-based virtual world for educational purposes. Similarly, Shen et al. (2012) used a BIM model in conjunction with the 3D-Unity game engine to develop a training environment for HVAC rehabilitation and improvement. The sophistication of the virtual environments described in the literature range from relatively simple, shared common data environments, parametric models and the collaborative features offered by BIM software (e.g. Comiskey et al. 2017) to virtual collaboration spaces resembling computer gaming environments with participants represented as avatars (e.g. Dossick et al. 2015).

The BIM-Enabled Learning Environment for Digital Construction (BENEDICT) project deals with how to teach courses at university level with BIM tools, in particular through the use of an IT platform comprising a BLE and an OLR repository for BIM models (Olowa et al. 2022, Ruutman et al., 2022, Witt, Kahkonen, 2019). The BLE developed by the BENEDICT project is a web-based platform and a repository that provides the following functions: BIM – functions (BIM model viewing, sharing and data extractuion); Virtual learning functions (user registration, learning materials hosting, feedback and assessment, file management); Collaboration functions (group formation and interactions); and storage of example project data, models and resources. A set of 3 pilot modules was developed to demonstrate the BLE, its functions and BIM-enabled learning workflow: BIM-enabled construction site organization; BIM-enabled project risk management; and BIM-enabled building design integration.

3. METHODS

Building Information Modelling creates a repository of technical data and information concerning the different stages of production of a building, i.e. concept design, space coordination and technical design (RIBA; 2020), construction and installation, including the whole life cycle (operation and maintenance, disposal). Learners will need OLR or Open Educational Resources (OER) (Unesco, 2019), that 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 for research purposes.

The OLR research addressed in this paper has been a part of a larger study where the aim has been to achieve knowledge and solutions for BIM-enabled learning. The BLE platform can be characterised as a complex Information System (IS) with human, organizational and technological dimensions (de Reuver et al., 2018). The principles and logic of IS design-science research have provided a methodological basis for the research on BLE and OLR as a part of it (Hevner & Chatterjee, 2010). The experimental research activities around information systems can be characterised as action research manoeuvres. This is a very helpful viewpoint for designing rigorous research steps. The Action Design Research (ADR) method combines organisational problem study, and construction and evaluation of IT artefact for the situation in question (Sein et al, 2011). The ADR research process is commenced with problem formulation that is followed by the iterations of Building, Intervention, and Evaluation (BIE).

Particular attention was put on establishing the BLE concept. This composed of four steps including desk study, interviews, validation workshop and assessment of technical solution possibilities (Witt et al, 2023). Next, system design methodologies were applied for forming the BLE platform architecture. Creation of the BLE IT solution was an iterative multi-phase research process where core and boundary components were developed and continuously evaluated and elaborated. The understanding over needs and possibilities arises from practitioners, end users, their organizations and relating public and private stakeholders. Exploring these various players resulted in clarifying the BLE system vision, its requirements, and constraints. The early BLE versions were evaluated (tested) by researchers, and with more matured versions (e.g. alpha and beta versions) specific evaluation arrangements were defined for having feedback from practitioners and end users.

The research addresses the development of the BLE and OLR along the principles and process described in Figure 1. Firstly, the BLE concept was elaborated through a four-step process involving a desk study, interviews with stakeholders and a validation workshop to identify functional requirements. The functional requirements were then interpreted in terms of technical requirements and a prototype BLE platform design. Thirdly, the BLE was elaborated as a core platform (a customized Moodle installation) and boundary IT solutions that included the OLR repository. The OLR solution originates from the overall vision and theoretical premises of BLE. Its functional and technical requirements are based on survey and interviews amongst industry representatives and education experts. System design methodologies and interface design were applied to constructing the OLR solution. The artefact designs and prototypes were evaluated by researchers in the first stages and finally by end users – teachers and learners using the pilot courses which were designed and trialed to test BLE and OLR performance and limitations. Figure 1 also indicates possible further advancements, for example, in terms of BLEs fine-tuned for specific disciplines.

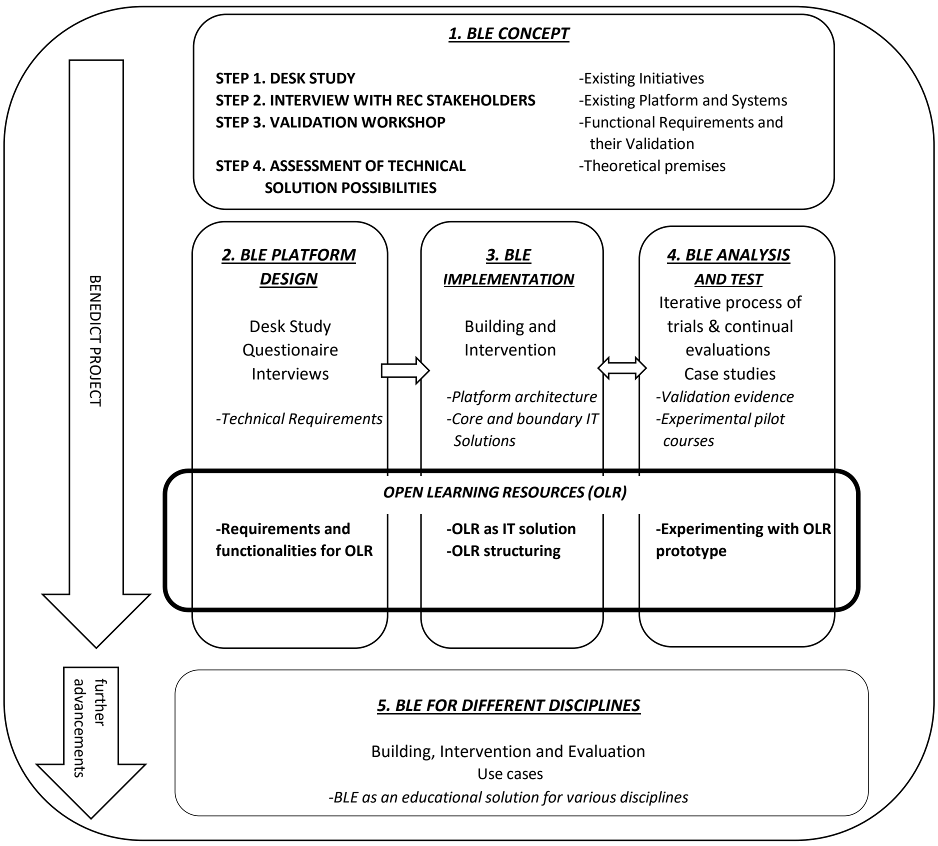

Figure 1: Multi-phase research process for addressing Open Learning Resources (OLR) as a part of the overall BLE research manoeuvre.

4. FINDINGS

4.5 BIM-Enabled learning environment requirements and concept

An initial list of 16 functional requirements for a BLE were identified from a desk study of the current educational-technological systems in use at the three partner universities. This list of requirements was elaborated on the basis of 31 semi-structured online interviews carried out in Italy (12 interviews), in Estonia (10 interviews) and in Finland (9 interviews) in the spring of 2021 among AEC stakeholders involved in education and/or training. The interviewees' affiliations were:

- 15 affiliated to Higher Education Institutions;
- 14 affiliated to the Construction (AEC) Industry;
- 2 affiliated with the Real Estate / Facilities Management Industry.

A thematic analysis of their responses, together with the initial functionalities identified from the desk study study led to the compilation of a list of 30 functional requirements. This list was subsequently the focus of a (virtual) validation workshop held in June 2021 at which BIM educators and others interested in BIM-enabled education and training from 5-countries (Estonia, Finland, Italy, Nigeria, Sri Lanka) participated. A detailed analysis of the interviews, validation workshop and emergent functional requirements are reported by Olowa, et al. (2022).

Table 1: Validated Functional Requirements for a BLE Mapped to IT Technical Solutions.

+	**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
	[Common Data Environment (CDE) for project data]
Integrations with specific BIM solutions	[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)

The emerging validated functional requirements (see Table 1) were then mapped to IT technical solution types in consultation with key informants. The key informants were technical experts in BIM and/or educational technology systems from each of the partner universities. They were presented with the list of validated functional requirements and asked to give recommendations of how these functionalities could be delivered through a BLE. Their recommendations are summarized in Table 1.

No technical solutions were offered for 3 of the identified and validated BLE requirements:

- 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 were acknowledged to be potentially useful features but potential technical solutions for them would need to be considered once they were more clearly defined.

The BLE system design concept (Figure 2) followed directly from the findings above and a prototype was built on the basis of a custom Moodle installation integrated with DiStellar BIM viewer to enable basic BIM functions (BIM model viewing, annotating, data extraction, etc.).

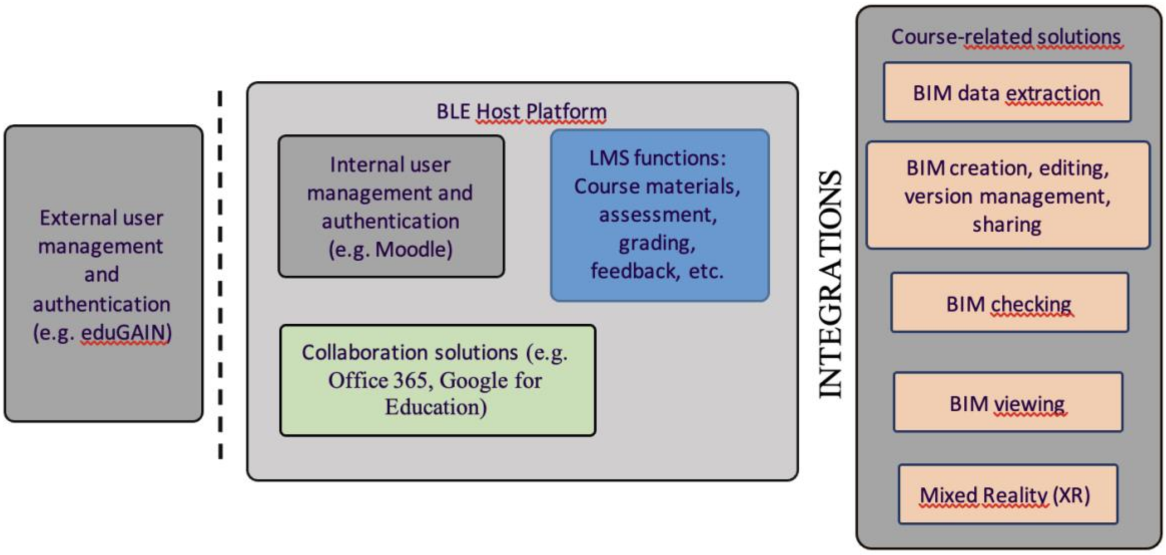

Figure 2: BIM-enabled Learning Environment System Design Concept.

4.6 Open learning resources and virtual data environment

The simulation of actual design and project management activities that takes place in teaching AEC modules with BIM as a medium has the need for a Common Data Environment. A Common Data Environment (CDE) is a single source of information for any given project, used to collect, manage, and disseminate all relevant approved project documents for multidisciplinary teams in a managed process (BS EN ISO 19650). A CDE has four different environments where models and data can be stored: the work in progress area, the shared area, the published area and the archive. With the aim of creating a virtual environment for learning and teaching activities two different virtual environment were developed, the BLE host platform and the OLR repository. The OLR repository is not a CDE because it does not fulfill the requirements of ISO 19650, but was developed with the aim of storing BIM models and data. The BLE host platform and the repository create a virtual environment where teachers, learners and system administrators can store data, reports and information concerning architecture and engineering systems of the built object under design. All of these technical data and information concerning the different stages of production of a building, design, i.e. concept design, space coordination and technical design, construction and installation, operation and maintenance allow users to create the BIM model. Construction Management students, as an example, will need to use a set of case studies to be tested with practical exercises. OLR or OER will be supplied as actual case studies – each case consisting of a building or a facility that has been designed and engineered in industry or in previous courses. The BLE, will be used to store and manage both OLR and BIM models, the inputs to and outputs of the students' work. Therefore, the BLE will provide a virtual environment where educational activities in the AEC sector can be performed using BIM-based technology. OER include 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, 2019). 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. The OLR are essential for users to benefit from the BLE as they provide real (or near-real) project data for learners to work with and this will demonstrate the practical implementation of BIM workflows. The BLE requires a repository of OLR that can be descriptions of projects, technical BIM models, and project plans (Table 2).

It is important that OLR for BLE are checked before model processing. BIM models should be checked for the achievement of the desired level of detail / level of development (LOD) and quality assessment consisting in code checking and model checking. The purpose of defining the level of information need is to prevent delivery of too much or too little information (ISO 19650-1:2018). In particular, the Project Information Requirements (PIR), in relation to the delivery of an asset indicate for what, when, how and for whom information is to be produced. The Level of Information Need (LOIN) has to be set by applying the BS EN 17412-1 that indicates the framework to set the LOIN. Firstly, four pre-requirements addressing the context needed to identify the information content have to be set: BIM uses, milestone, actors, object. After this stage, the LOIN must be set concerning geometrical information, alphanumerical information, and documentation (BS EN17412-1:2020).

In the specific case of construction management-oriented applications, OLR 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 teachers or by the BENEDICT project associated partners. As an example, the following documentation / information can be produced by the students of construction engineering and management courses with BIM.

- Project Planning, job site design & safety planning;
- Work Breakdown Structure;
- Construction project schedule;
- Construction site design;
- 4D BIM animation.

Table 2: Types of Open Learning Resources.

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; (…)

4.7 OLR categorization

The BLE virtual environment has the task of integrating BIM strategy and technologies into curricular activities, i.e. course modules. The BLE environment consists of the BLE Host Platform, that hosts pilot modules OLR and a Repository that includes a Content Management System and a server that hosts BIM models and other OLR (Figure 3).

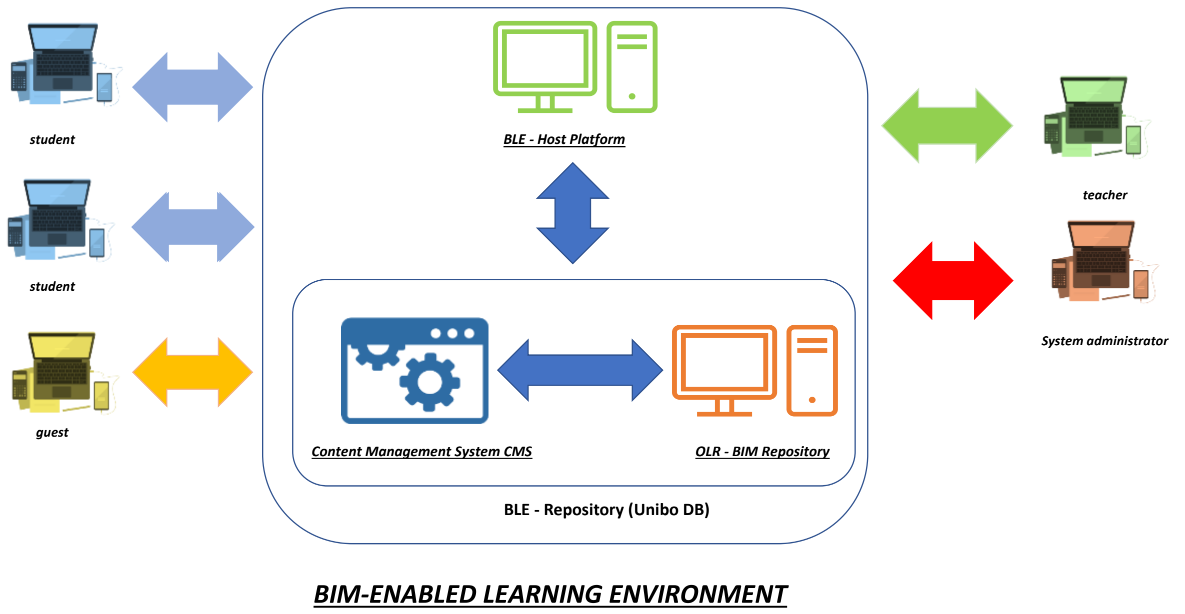

Figure 3: BIM-enabled Learning Environment (BLE) – system architecture.

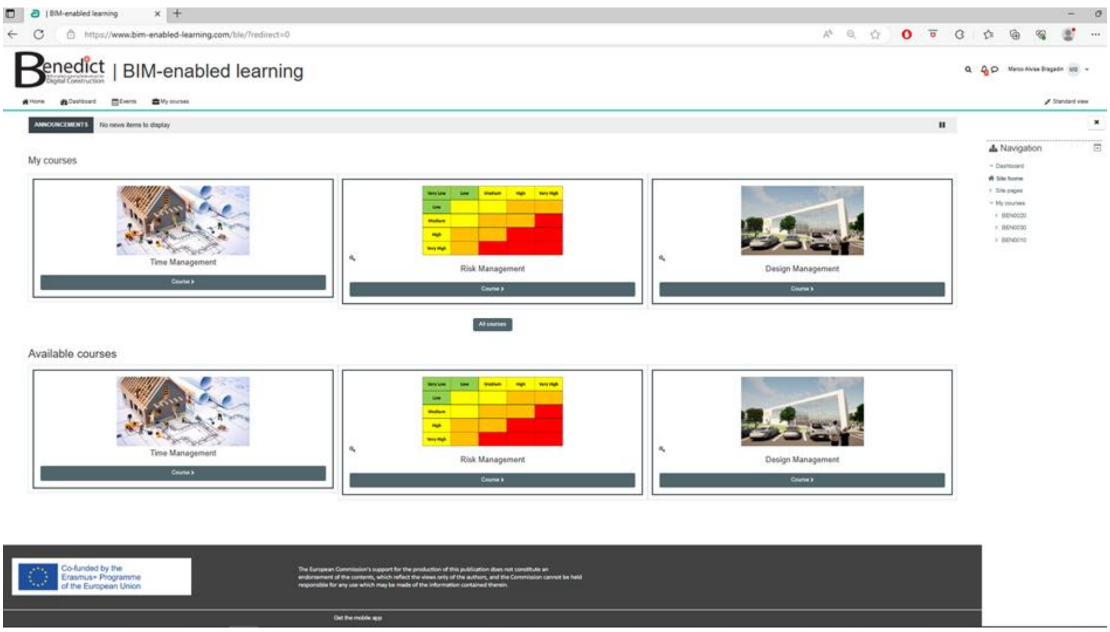

Figure 4: BIM-enabled Learning Environment (BLE) Host Platform.

The pilot modules section addresses the different pilot modules of the BENEDICT project: integrated design module, risk management module and time management module (Figure 4). The Repository includes a Content Management System (CMS) and a Data base (DB) for storage of OLR and students'outputs, (Figure 5). Both sections can be used by different actors, with different navigation capacities, depending on the type of user, teacher, learner, and system administrator (as shown in Figure 3).

The navigation capacity is of capital importance as it depends on data and BIM object categorization. BIM models can be classified as types of models and model elements. All models are composed of model elements that have properties and attributes. Each native BIM authoring tool, as well as IFC, uses its own unique terminology to describe these components. It is therefore important to first understand what is considered an element and how elements relate to one another in order to discuss them.

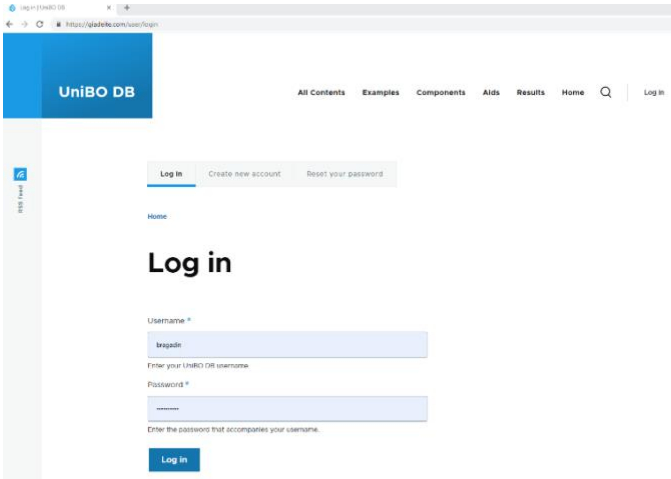

Figure 5: Open Learning Resources (OLR) - BIM repository (Unibo DB).

Due to the complexity of buildings and BIM models, a simple hierarchy does not suffice to describe the relationship between model elements (US GSA BIM Guide 07). A sophisticated ontology is required to develop an understanding of how model elements may relate to one another. All the levels in the model ontology have properties associated with them, and thus the properties of one model element are associated with related model elements. A BIM ontology is an informal, semi-structured, conceptual domain ontology used for knowledge acquisition and communication between people.

Categorization is of capital importance to achieve effective information management. Classification can be defined as: "The act or process of dividing things into groups according to their type". Uniclass is based on the general structure described in ISO 12006, which promoted the use of classification classes, each of which relates to a classification need. As well as products (or objects), some of the other classes suggested by ISO 12006 are:

- Entity e.g. a building, a bridge, a tunnel;
- Complex (a group of entities) e.g. airports, hospitals, universities, power stations;
- Space e.g. office, canteen, parking area, operating theatre;
- Product e.g. boiler, door, drain pipe;
- Facilities, this combines the space with an activity which can be carried out there, for example, an operating theatre;
- Other classes can be added, such as 'system', which works very well in an MEP environment. Similarly, an 'activities' class would be very helpful for defining a range of activities which might be able to be done within a particular space, as an alternative to using the 'facilities' class.

The organization of information about construction works is essential for BIM, and a framework for classification is proposed by ISO 12006 standard as shown in the following tables (Table 3). Information relevant to particular stages in a building construction project, therefore, life cycle stages should be defined on a common basis. Building life cycle stages proposed by ISO standards are the following: inception; brief; design; production; maintenance and demolition. These principal stages are further decomposed to provide a meaningful set of stages for exchange requirements.

Different classes of information are proposed by the ISO 12006 standard, related to resources, as construction information, products, agents and aids; or related to process as management and the construction process; related to the result as construction complex, entity, built space, element and work result; or related to property (Table 4).

Table 3: Standard principal and decomposed life cycle stages (ISO 12006-2:2015).

Life cycle stage	Principal life cycle stage	Decomposed life cycle stage
Pre-life cycle stages	Inception	Portfolio requrements
	Brief	Conception of need
		Outline feasibility
		Substantive feasibility
Pre-construction stages	Design	Outline conceptual design
		Full conceptual design
		Coordinated design and procurement
Construction stages	Production	Production information
		Construction
Post-construction stages	Maintenance	Operation and maintenance
	Demolition	Disposal

Table 4: Framework for classes of information about construction works (ISO 12006-2:2015).

Class	Classified by
Classes related to resource	
Construction information	Content
Construction product	Function or form or material or any combination of these
Construction agent	Discipline or role or any combination of these
Construction aid	Function or form or material or any combination of these
Classes related to process	
Management	Management activity
Construction Process	Construction activity or construction process life cycle stage or any combination of these
Classes related to result	
Construction complex	Form or function or user activity or any combination of these
Construction entity	Form or function or user activity or any combination of these
Built space	Form or function or user activity or any combination of these
Construction element	Form or function or user activity or any combination of these
Work result	Form or function or user activity or any combination of these
Classes related to property	
Construction property	Property type

Table 5: Some examples of BIM classification.

BIM oriented classification	BIM community Classification System
• Uniclass • OmniClass • MasterFormat • UniFormat • CoClass • CCS • TALO 2000 • NS 3451 & TFM • Industry Foundation Classes • Building SMART Data Dictionary • ETIM	• Language • Type • Project: o Implementation o Research o Collaborative initiative o Other • Category: o 3D – Virtual Design & Construction o Lean & Industrialized Construction o Planning and budgeting o Subcategory ▪ Strategies ▪ Edification ▪ Project ▪ Workflows

The framework for classification of ISO 12006 about construction works also introduces a set of different relationships between the different classes of information. The organization model or user activity of the built asset uses the built space that is defined by a construction result, that is part of a construction complex. A construction complex is an aggregate of construction entities, composed by construction elements. A construction result is developed by a construction process that is divided into pre-design, design, production and maintenance processes. The construction process uses construction resources that can be construction product, construction aid, construction agent and construction information (ISO 12006-2:2015). Classifying data means structuring them in an agreed way so that different actors can easily find what they need and understand it. A classification system is like a common language. In BIM, classification lets people, software and machines share and use building information efficiently and accurately. Different classification systems have been developed for different types of BIM data and actors, and for different geographic areas and situations. In Table 5 some other examples of BIM classification are presented.

As a first approach in the development of the OLR repository, the following classification systems for BIM models were proposed for the BLE platform: metadata, building type, size of the project, different plans, life cycle period, model categories, model functions, language/country. Metadata classification was chosen as the easiest way of OLR categorization. Many metadata of BIM models can be detected, and different categories of information can be listed in the repository for each piece of OLR. A list of metadata of BIM education models is presented in Table 6.

The OLR repository for the BENEDICT BLE (UNIBO DB) is a prototype for an online BIM models repository (Figure 5; Figure 6). The general categorization system of BIM models can be based upon five categories: discipline, type of building project, life cycle stage, model use and BIM dimension (Figure 8).

Table 6: Metadata of BIM education Models. Part one.

Information Category	**Value Type**	**Values**	**Description**
Model Language	Text	English, Finnish, Estonian, Italian	The language(s) used in the model to describe the content
Building Type	Text	Office, Teaching, Care, Residential	Property used to describe the dominant function/use case for the facility
Discipline	Text	Urban, Architecture, Landscape, Interior Design, Structural Engineering, Building Services Engineering (HVAC and MEP), Construction Engineering, Facility Maintenance	The model discipline prepared by or for the purpose of the given discipline.
Program	Text	Small, Medium, Large	Reflecting on the size of the building, relative to its building type.
Model Categorization	Text	Mass, Room/Space/Zone, and Element models	The type of model content

Table 6: Metadata of BIM education Models. Part two.

Information Category	**Value Type**	**Values**	**Description**
Life-Cycle Stage	Text	Strategic Planning, Brief, Programming, Schematic Design, Preliminary Design, Design Development, Detailed Design, Pre-Construction, Construction, Commissioning, Hand-Over, Use, Renovation, Disassembly, Demolition	The stage of the model prepares in or for
Model Use	Text	Gather, Generate, Analyze, Communicate, Realize	Penn state classification for BIM uses
Model Maturity	Text	Initial, Defined, Managed, Integrated, Optimized	The mature of the model in any specific stage.
Geometry Maturity	Text	Symbolic, Generic, Detailed, Fabrication	Average accuracy of geometry in the model.
Model Information Reliability	Text	Preliminary, Proposed, Coordinated, As-Built	The state of the information in the model, its reliability with respect to itself and others in the process
Content Classification	Text	CCI, Uniclass, Masterformat	

A prototype for Unibo DB server that hosts the CMS and the OLR database was developed for the proposed online BIM models repository of the BENEDICT project (http://ble.unibo.it). In the welcome page (Figure 6) it is possible to download a guideline to help end users better use the platform. Actually, the CMS works with the categorization system displayed in the UNIBO DB based upon four main categories of OLR, termed records: examples, components, aid and results. Each record has different fields of categorization, that can be required or not, and can be of different types and formats (Figure 7, Figure 8).

From the home page, end users can access several sub-pages including “Examples”, fully solved BIM solutions that students can use as examples, “Components” or BIM objects, “Aid” including BIM documentation, standards, project data, and “Results” where students’ outputs are stored. The repository also provides a powerful search engine to help quickly find useful information from the repository.

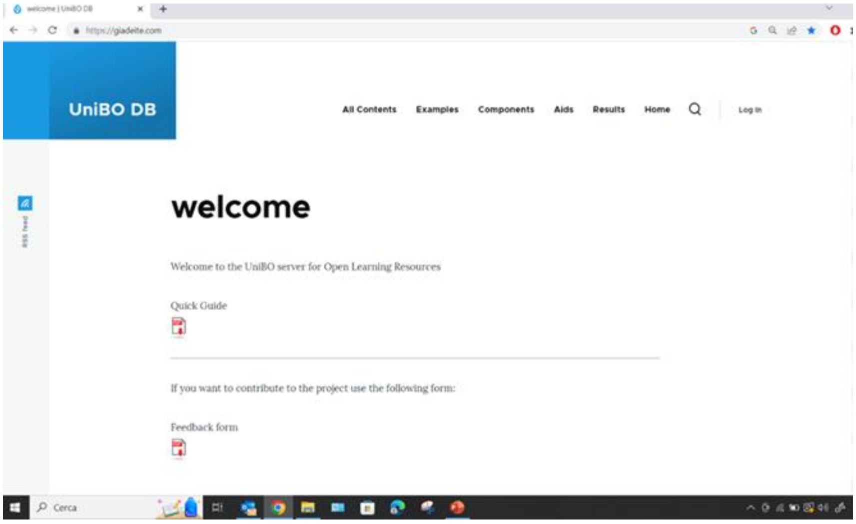

Figure 6: BENEDICT DB – Unibo server and project data repository.

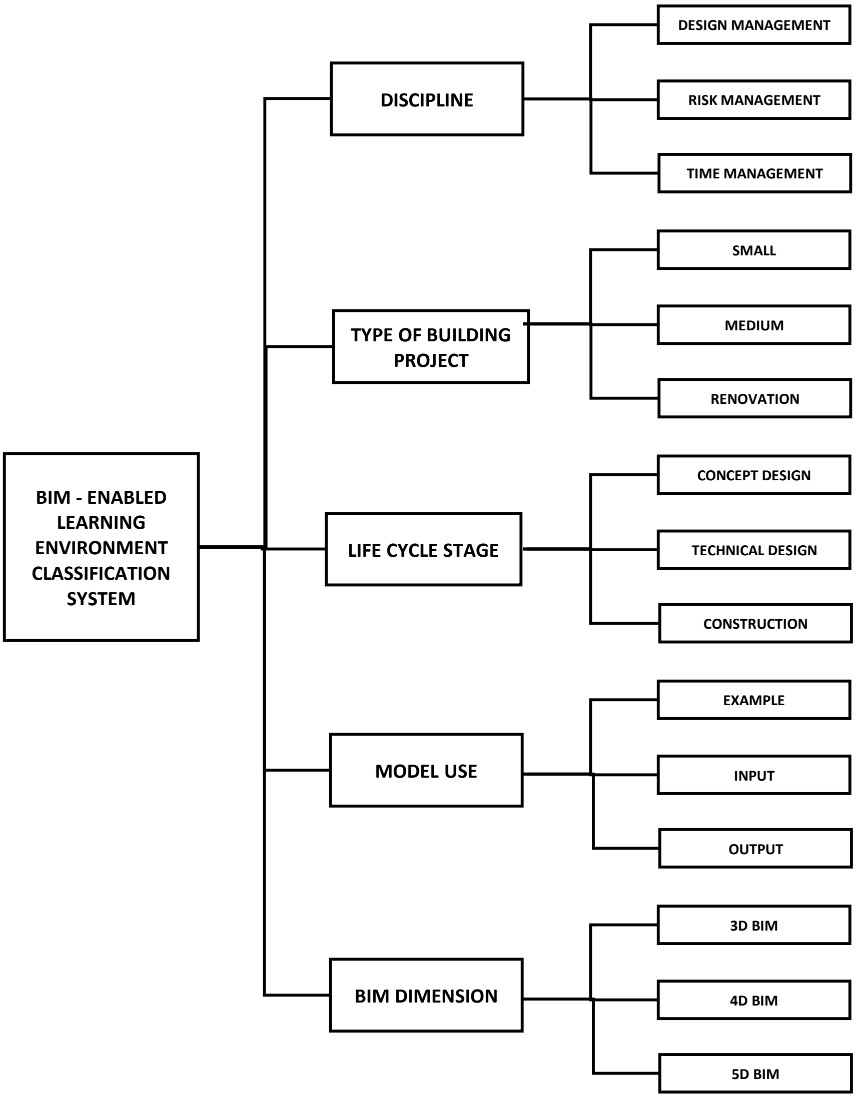

Figure 7: BIM-enabled Learning Environment (BLE) categorization.

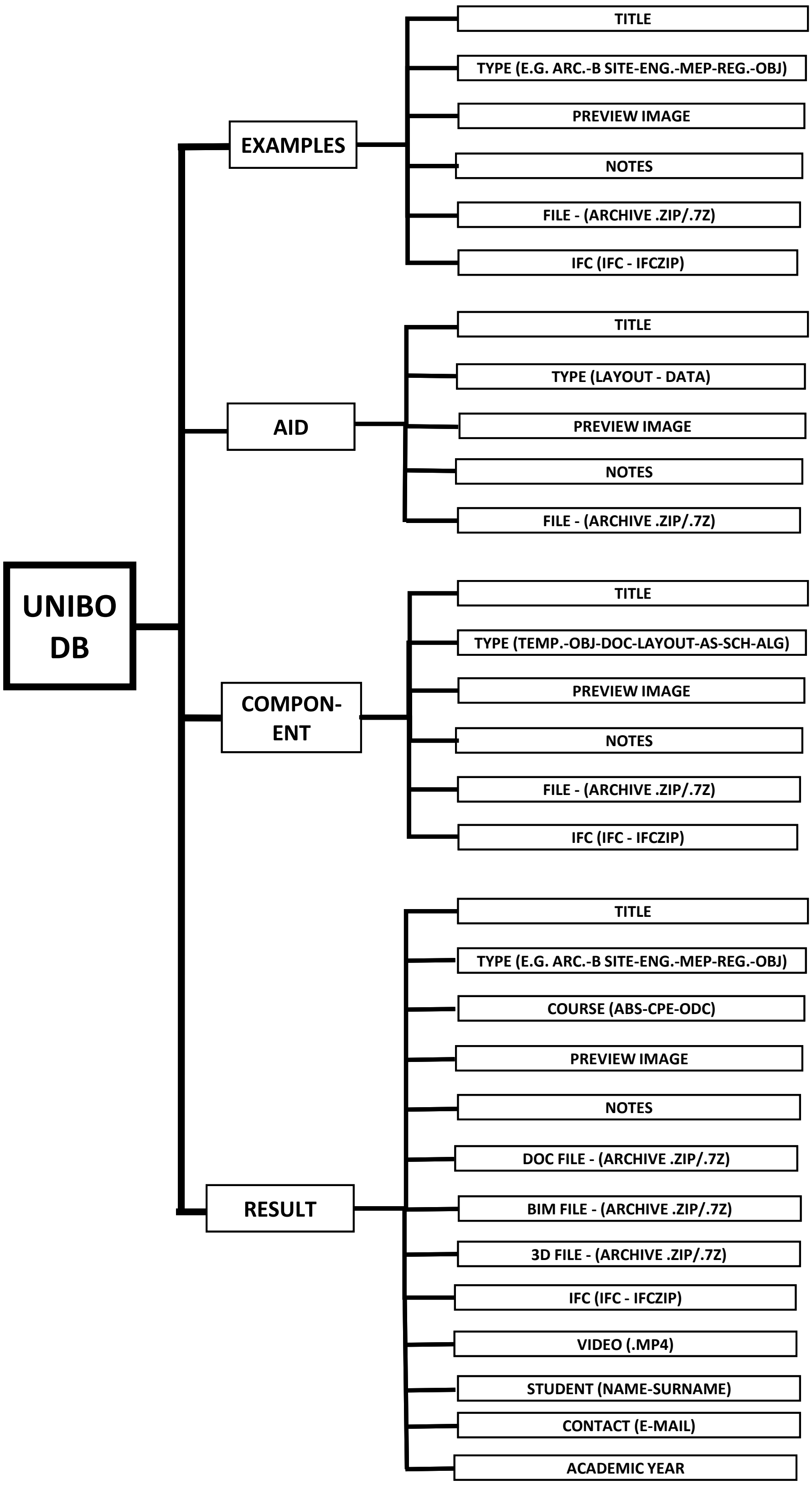

Figure 8: Unibo DB categorization.

5. DISCUSSION

Three modules offering Design Management, Time Management and Risk Management taught using a BIM-enabled educational approach were piloted with the intention of demonstrating the concept of BIM-enabled learning and the functioning of the BLE and OLR within real taught courses. They were co-developed by the 3 partner universities during the second year of project implementation (2021-2022) in collaboration with the Centre for Engineering Pedagogy at TalTech which also led the development of evaluation and assessment tools for BIM-enabled learning. The design and content of all 3 pilot modules were demonstrated along with the BLE platform to a wide range of stakeholders at two Multiplier Events (in Tallinn in June 2022 and October 2022). The actual teaching of the pilot modules to students took place during the 2022/2023 academic year. In the case of teaching the Design Management module in Tampere, this implementation took place in parallel with the finalization of the assessment and evaluation tools. Consequently, the student and teacher feedback received for the Design Management module took a different form to the feedback received in relation to the Time and Risk Management modules which were implemented slightly later by which time the evaluation and assessment tools had been finalized. In the case of all 3 pilot modules, the feedback received from both teachers and students was highly positive. This confirmed the effectiveness of BIM-enabled learning as an appropriate innovation for knowledge and skills development in the REC sector. It also serves to validate the usefulness of the BLE and OLR repository.

By developing a prototype BLE and OLR, the BENEDICT project directly addressed the opportunities to realise the potential of BIM as a virtual project environment and promoted learning that emphasized interdisciplinary collaboration. With the OLR, the specific problem of the shortage of appropriate BIM models for education (as noted by Puolitaival and Forsythe, 2016) was alleviated. The BLE with integrated OLR responded to the need for a purpose-built BIM-enabled learning environment. The need for an educationally-oriented common data environment in the form of an OLR has been demonstrated in the delivery of these pilot modules and the prototype OLR described in this research continues to be developed and expanded. Like the BLE, it serves as an example for others and can easily be replicated and further developed by others. In its current, prototypical form, the BLE and OLR repository have no obvious limits in terms of the potential for scaling them up as the underlying systems (Moodle of the BLE, Drupal for the OLR repository) are capable of and already widely used in large-scale applications. However, there are many specific, learning-experience related limitations and for these to be identified, analyzed and overcome, it is necessary for developers (of future BLEs, of educational learning experiences and of OER) to experiment with and adapt their own BLE systems and content.

6. CONCLUSIONS

In conclusion, Building Information Modelling (BIM) has become increasingly important in the field of Architecture Engineering and Construction (AEC), particularly for construction simulation and project construction management. The availability of data, reports, and information is crucial for students, teachers, and operators in the AEC industry to create BIM models. The BENEDICT project, a European Erasmus plus KA2 project, developed a web-based platform for BIM teaching that is closely connected to the AEC industry. This platform, known as the BIM-enabled Learning Environment (BLE), provides a repository for BIM models, open learning resources (OLR), and students' outputs that includes a Content Management System (CMS) and a Data Base (DB). The CMS and the DB are freely accessible to registered users who can access OLR that are essential for BIM-enabled learning processes and provide real-life project data for learners to work with. Within the BLE, the OLR repository (UNIBO DB) categorizes BIM models and elements, allowing for effective information management and knowledge transfer between different players in the AEC industry. By incorporating OLR and BIM workflows, the BLE platform enhances learning experiences and supports the implementation of BIM-based project planning and control. Ultimately, the BENEDICT project, the BLE and OLR contribute to bridging the productivity gap in the construction industry by promoting the use of BIM and providing a collaborative learning environment for students and future practitioners.

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