CONVR 2023

Proceedings of the 23rd International Conference on Construction Applications of Virtual Reality

MANAGING THE DIGITAL TRANSFORMATION OF CONSTRUCTION INDUSTRY
University of Florence, Florence, Italy, November 13-15, 2023

edited by
Pietro Capone, Vito Getuli,
Farzad Pour Rahimian, Nashwan Dawood,
Alessandro Bruttini, Tommaso Sorbi

FIRENZE
UNIVERSITY
PRESS

PROCEEDINGS E REPORT
ISSN 2704-601X (PRINT) - ISSN 2704-5846 (ONLINE)

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MANAGING THE DIGITAL TRANSFORMATION OF CONSTRUCTION INDUSTRY

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FIRENZE UNIVERSITY PRESS
2023

CONVR 2023 - Proceedings of the 23rd International Conference on Construction Applications of Virtual Reality : Managing the Digital Transformation of Construction Industry /edited by Pietro Capone, Vito Getuli, Farzad Pour Rahimian, Nashwan Dawood, Alessandro Bruttini, Tommaso Sorbi. - Firenze : Firenze University Press, 2023.

(Proceedings e report ; 137)

https://books.fupress.com/isbn/9791221502893

ISSN 2704-601X (print)
ISSN 2704-5846 (online)
ISBN 979-12-215-0289-3 (PDF)
ISBN 979-12-215-0257-2 (XML)
DOI 10.36253/979-12-215-0289-3

Graphic design: Alberto Pizarro Fernández, Lettera Meccanica SRLs
Front cover image: *Ad Alto Angolo Di Paesaggio Urbano,* by Pixabay/Pexels.com, https://www.pexels.com/it-it/foto/fotografia-ad-alto-angolo-di-paesaggio-urbano-208213, CC0 1.0 Universal

The Proceedings of the CONVR2023 are published with the contribution of the University of Florence, which hosted and partially funded the Conference, and Teesside University that collaborated with its organization.

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The online digital edition is published in Open Access on www.fupress.com.

Published by Firenze University Press
Firenze University Press
Università degli Studi di Firenze
via Cittadella, 7, 50144 Firenze, Italy
www.fupress.com

This book is printed on acid-free paper
Printed in Italy

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 published by Firenze University Press, ISBN 979-12-215-0289-3, DOI 10.36253/979-12-215-0289-3

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Foreword

The *International Conference on Construction Applications of Virtual Reality* (CONVR), as one of the world's leading conferences in the areas of immersive realities and digital transformation in AECO Industry, and the local organizing committee are pleased to present the Proceedings of the 23rd International Conference on Construction Applications of Virtual Reality (CONVR 2023) with the overarching theme "MANAGING THE DIGITAL TRANSFORMATION OF CONSTRUCTION INDUSTRY".

The 23rd CONVR was held on November 13-15, 2023, in Florence, Italy and was proudly hosted by the Department of Architecture of the University of Florence.

CONVR 2023 brought together AECO researchers and practitioners from around the globe to report on and exchange the latest development, ideas, improvements and applications stemming from innovative research activities in the following fields: *Virtual Reality (VR) and Augmented Reality (AR), Reality capture and Photogrammetry, H-BIM for heritage management, Simulation and Automation techniques, Computer Vision and Image Processing, Linked Data and Semantic Web for Knowledge Management, Smart Contracts, Distributed Ledger Technologies and Blockchain, Data Science, Machine Learning, and Data-Driven Approaches, Health & Safety, Green and smart buildings, Occupant-centric building design and operation, Building Information Modeling (BIM), Digital Twins, Internet of Everything, Mobile and wearable computing, Construction site management*. Those topics were articulated in eight different areas: *Methodology, Technology transfer, Technology, State of Art, Theoretical Study, Policy and Standardization, Education and Training, Case Study and Application*.

A total of 123 high-quality contributions were accepted after a rigorous review process from 71 esteemed members of the conference's International Scientific Committee. The accepted papers include a total of 374 authors from 32 countries, from Europe, the Americas, Asia and the Middle East.

More than 150 experts attended the conference contributing to enriching the exciting program which included 6 keynote speeches on the first day and 4 parallel presentation sessions on the following days, together with 5 workshop sessions.

The editors trust that this publication is stimulating and inspiring for academics, scholars and industry experts in the field; hoping that this could be a driving force for innovation, growth and global collaborations among researchers and stakeholders. We believe in the significant role that human interactions, networks, knowledge exchange and transfer play in developing high-value and groundbreaking research. This event provides a platform for networking and intellectual exchange of ideas.

We take this opportunity to express our gratitude to the CONVR2023 Technical Organizing Committee as well as our esteemed reviewers and sponsors. The creation of such a broad and high-quality conference program would not have been possible without their involvement and support. We also thank all the authors who dedicated much of their time and efforts to contribute to CONVR2023. We extend our best wishes to you and look forward to seeing you next year for CONVR2024.

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 published by Firenze University Press, ISBN 979-12-215-0289-3, DOI 10.36253/979-12-215-0289-3

BIM-BASED OPEN LEARNING RESOURCES REPOSITORY FOR THE BENEDICT PROJECT

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ABSTRACT: *In the field of AEC, Architecture Engineering and Construction, Building Information Modelling 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 the availability of data, reports, pieces of information that allows to create BIM. "BENEDICT" is an European Erasmus project that has the aim of developing a web-based platform for BIM teaching that has a tight relationship with the AEC industry. Therefore, 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 and for research purposes. In addition to the BLE platform, a BIM-model repository was developed to store information for each component of the project and of the learning activities. The repository can also store OLR and students' outputs. The BLE repository has the task of helping students and practitioners to implement BIM actual project models by developing an on-line repository of digital models, objects and elements, therefore providing knowledge transfer between different players.*

KEYWORDS: *Building Information Modelling, Benedict project, Open Learning Resources, Construction.*

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, the industry 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). Building Information Modelling (BIM) is 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, everything 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. Therefore, BIM is a method or strategy, not a tool. In the construction sector, knowledge transfer between different players, owner, 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 there 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 Architecture, Engineering and Construction sector. The use of BIM is spreading rapidly in many countries, covering a wide range of project both in the public and private sectors. Digitization of construction sector involves the need of helping students and practitioners to implement BIM 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 of developing a shared, online BIM models repository 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 BENEDICT project, BIM-Enabled Learning Environment for Digital

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FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)
Marco Bragadin, Caterina Morganti, Pier Carlo Ricci, Emlyn Witt, Kalle Kähkönen, Puolitaival Taija, *BIM-Based Open Learning Resources Repository for the Benedict Project,* pp. 254-265, DOI 10.36253/979-12-215-0289-3.24

Construction, 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 for BIM models (Olowa et al. 2022, Ruutman et al., 2022, Witt, Kahkonen, 2019). The fundamental needs of Real Estate and Construction professionals and students, Architects, Engineers, Construction Managers, concerning Building Information Modelling 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, poles, 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 i.e. elevators, mobile staircases,
- Construction project systems: i.e construction site provisions and equipment (e.g. scaffoldings, tower crane, formworks 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 BLE users – learners, teachers, system administrators – consist in having the availability of data, reports, pieces of information concerning architecture – engineering systems. The technical data and information concerning design, development and installation of the building and its project management allows BLE users to create the Building Information Model. For example, construction management students will need a set of case studies to be tested with practical exercises and the Open Learning Resources 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 repository, where all BIM models, examples and data can be stored and used. This creates a BIM enabled Learning Environment, BLE. The BLE provides the learning environment or web platform specifically designed to support this type of learning. Key resources for the use of the BLE are Open Learning Resources.

2. OPEN LEARNING RESOURCES AND VIRTUAL DATA ENVIRONMENTS

The simulation of actual design and project management activities that takes place in teaching AEC modules with BIM as a media has the need of 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 platform and the OLR repository. The OLR repository is not a CDE because does not fulfill the requirements of ISO 19650, but was developed with the aim of storing BIM models and data. The BLE platform and repository create a virtual environment where teachers, learners and system administrators can store data, reports, pieces of 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 allows user to create the Building Information Model. Construction Management students, as an example, will need to use a set of case studies to be tested with practical exercises.

Open Learning Resources (OLR) or Open Educational Resources (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, output of the students' work. Therefore, the BIM – Enabled learning environment will provide a virtual environment where educational activities in the AEC sector can be performed using BIM-based technology. 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, 2019). 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. The BENEDICT project has the aim of promoting a new concept of learning/training in the REC sector. The Open Learning Resources 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 BIM-enabled learning environment creates a repository of OLR that can be descriptions of projects, technical BIM models, and project plans (table 1).

Table 1: Type 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; (…)

Open learning resources for BLE need to be checked before model processing. BIM models should be checked also concerning 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 level of information need must be set concerning geometrical information, alphanumerical information, and documentation (BS EN17412-1:2020) (figure 1, figure 2). 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 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 Building Information Modeling.

- Project Planning, job site design & safety planning;
- Work Breakdown Structure;

– Construction project schedule;
– Construction site design;
– 4D BIM animation.

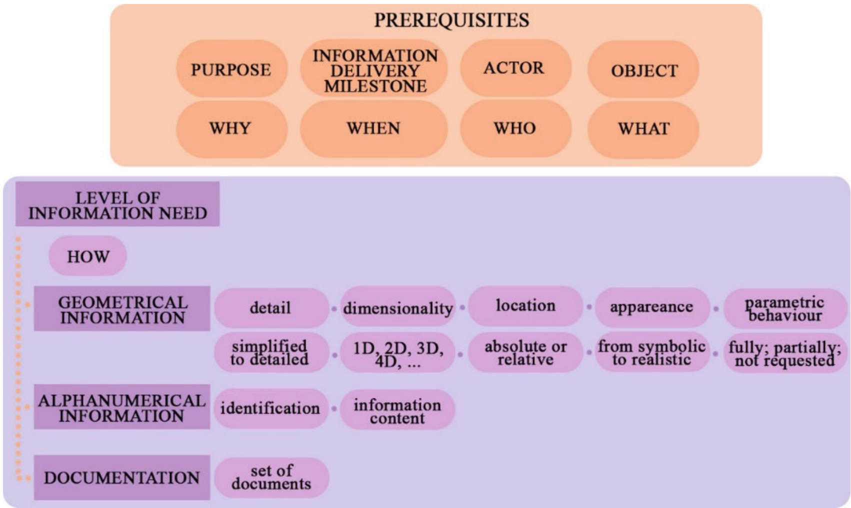

Fig. 1: Relationship diagram on level of information need.

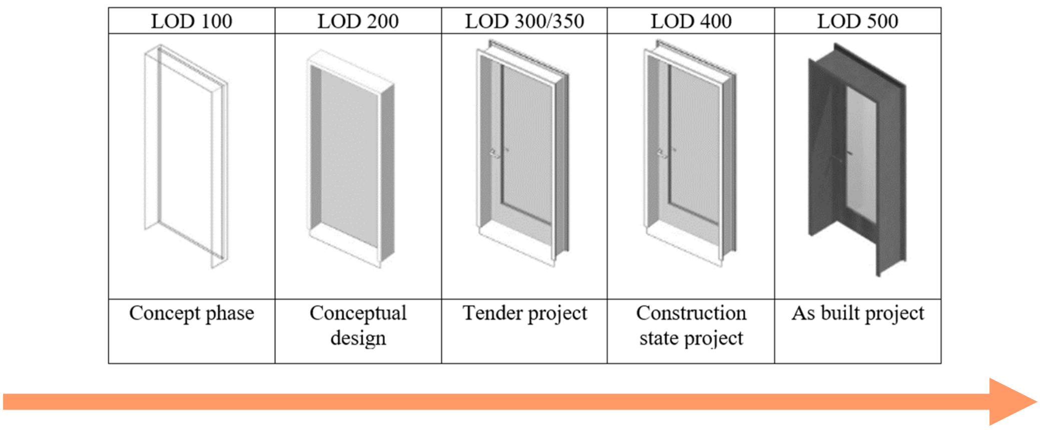

Fig. 2: Example of the concept of "continuum" associated to the detail of a door.

3. BIM ENABLED LEARNING ENVIRONMENT AND OLR CATEGORIZATION

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

The navigation capacity is of capital importance as 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.

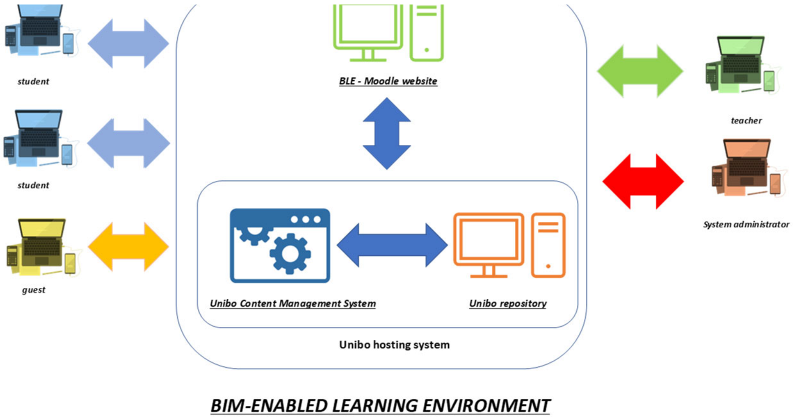

Fig. 3: BIM-enabled Learning Environment (BLE) – system architecture.

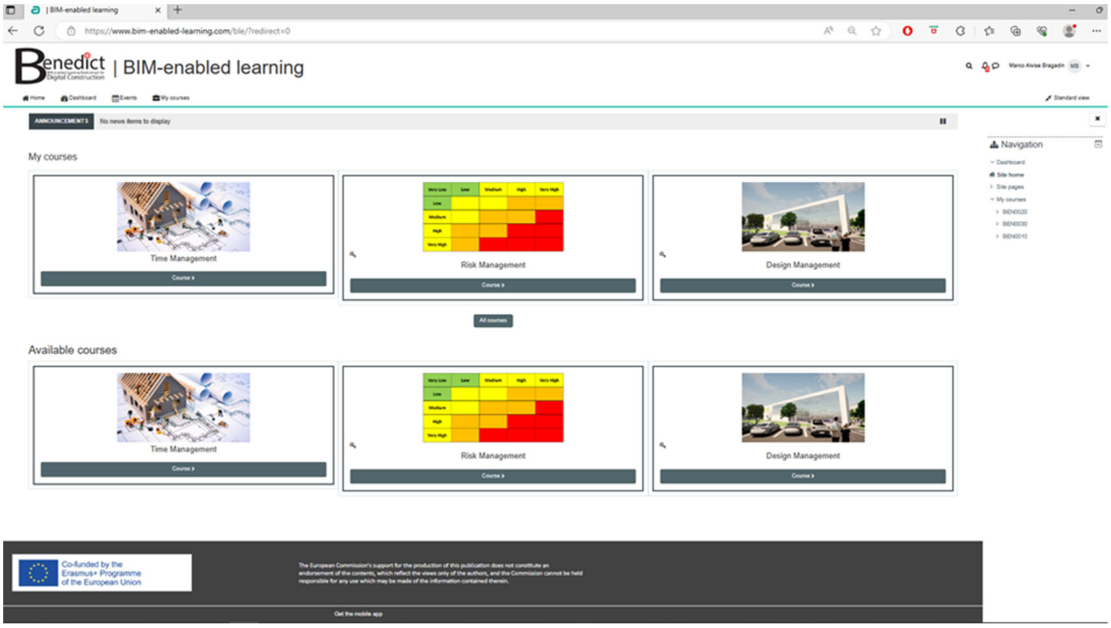

Fig. 4: BIM-enabled Learning Environment (BLE) – BLE platform.

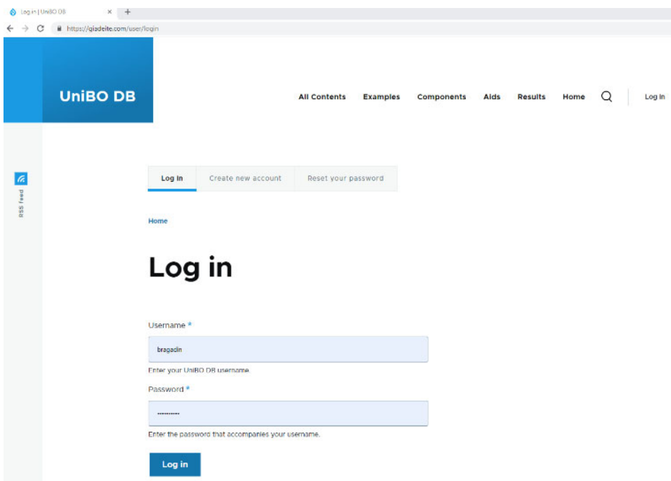

Fig. 5: BIM-enabled Learning Environment (BLE) – OLR repository.

Due to the complexity of buildings and BIMs, 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.

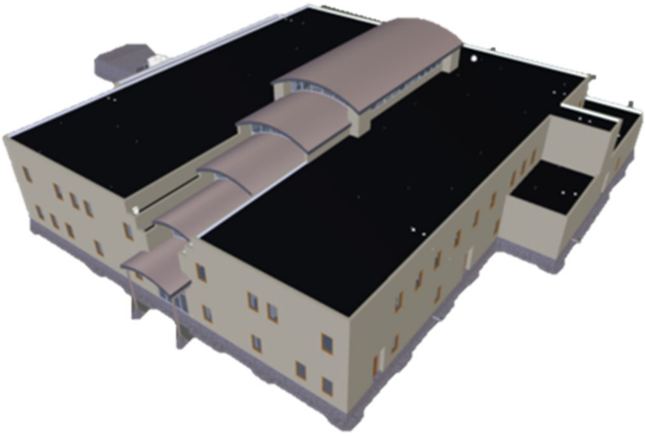

Fig. 6: Federated Model (from US GSA BIM guide 07).

A federated building information model is an assembly of distinct discipline models to create a single, complete model of the building. A federated model is a model composed of multiple linked models that contains architectural, structural, and mechanical, electrical, and plumbing (MEP) information of a building (US GSA BIM guide 07). Federation is the creation of a composite information model from separate information containers (ISO 19650 -1). A stand-alone model is a single discipline model, an information model that is a set of structured and unstructured information containers (ISO 19650 -1). The Association of General Contractor of America, AGC, in the AGC Consensus Docs 301- BIM Addendum (AGC, 2015) defines a federated model as a model consisting of linked but distinct component models, drawings derived from the models, texts, and other data sources that do not lose their identity or integrity by being so linked, so that a change to one component model in a federated model does not create a change in another component model in that federated model. A single federated model is useful for design co-ordination, clash avoidance and clash detection, approvals processes, design development, estimating and so on, but the individual models do not interact, they have clear authorship and remain separate. This means that the liabilities of the originators of the separate models are not changed by their incorporation into the federated model (fig. 6, fig. 7).

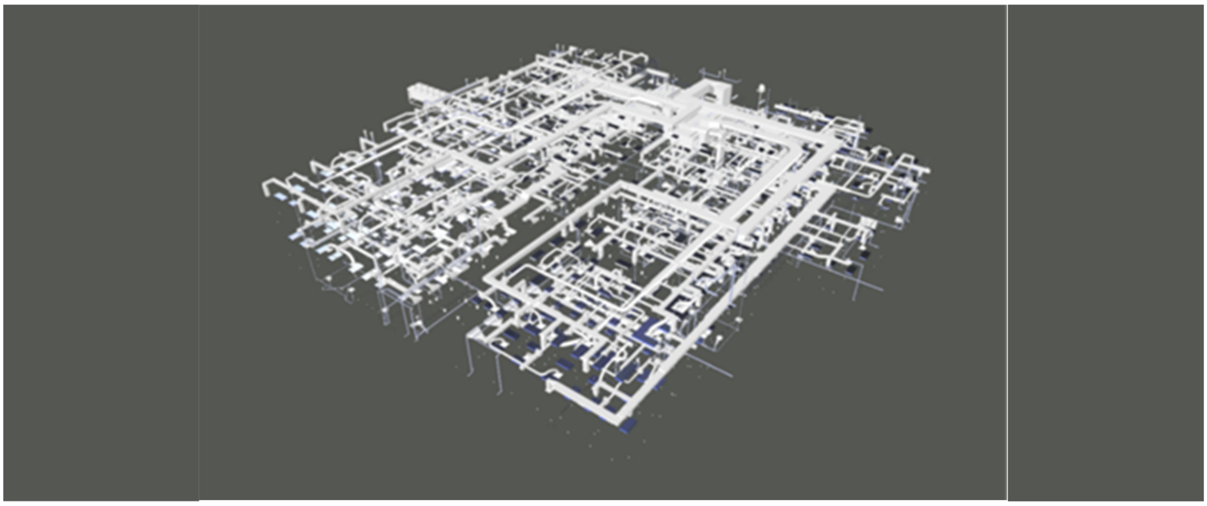

Fig. 7: Single discipline model- stand alone MEP Model of the Building (from US GSA BIM guide 07)

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 of capital importance for Building Information Modelling, therefore a framework for classification is proposed by ISO 12006 standard as showed in the following tables (table 2). Information are 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.

Table 2: 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

Different classes of information are proposed by ISO 12006 standard, related to resources, as construction information, products, agents and aids; or relatated to process as management and construction process; related to result as construction complex, entity, built space, element and work result; or related to property (table 3).

Table 3: 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 4: Some examples of BIM classification.

BIM oriented classification	BIM community Classification system

• Uniclass 2015
• OmniClass
• MasterFormat®
• UniFormat™
• CoClass
• CCS
• TALO 2000
• NS 3451 & TFM
• Industry Foundation Classes
• buildingSMART Data Dictionary
• ETIM
	• Language
	• Type
	• Project
	  ○ Implementation
	  ○ Research
	  ○ Collaborative initiative
	  ○ Other
	• Category:
	  ○ 3D – Virtual Design & Construction
	  ○ Lean & industrialized construction
	  ○ Planning and budgeting
	  ○ 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 results is developed by a construction process that is divided in pre-design, design, production and maintenance processes. 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 it 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 4 some other examples of BIM classification are presented.

Table 5: Metadata of BIM education Models.

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
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	

As a first approach the following classification systems for Open learning resources OLR 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. Again, a list of metadata of BIM education models is presented in table 5.

The BIM-enabled learning environment is a prototype for online BIM models repository (fig. 5; fig.8). The proposed categorization system of BIM models is based upon five categories: discipline, type of building project, life cycle stage, model use and BIM dimension (fig. 9).

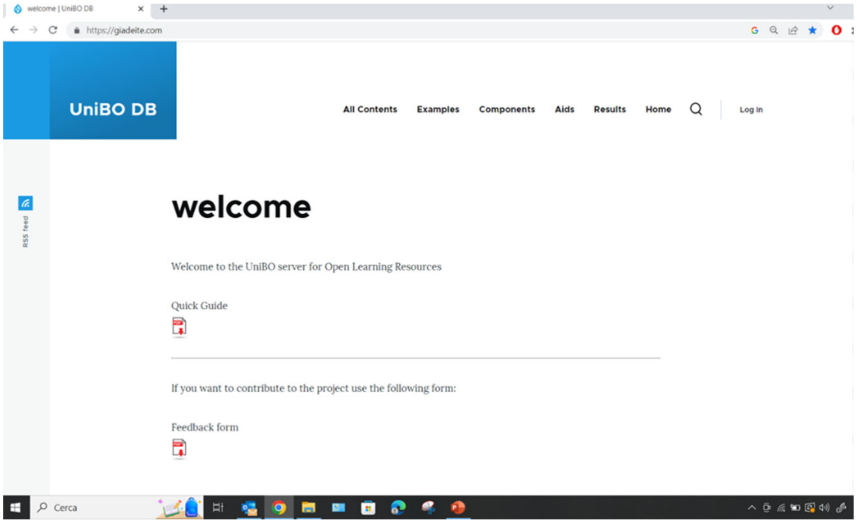

Fig. 8: BENEDICT DB – Unibo server and project data repository.

A prototype for Unibo server that host 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 (fig. 8) it is possible to download a guideline to help end users better use the platform . From the home page, end users also could 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 searching engine to help quickly find useful information from the repository.

4. 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, aims to develop 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 Manaagment System CMS and a Data Base. The CMS and the DB are freely accessible to registered users that can access OLR are essential for BIM-enabled learning processes and provide real-life project data for learners to work with. The BLE platform 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 and the BLE platform 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.

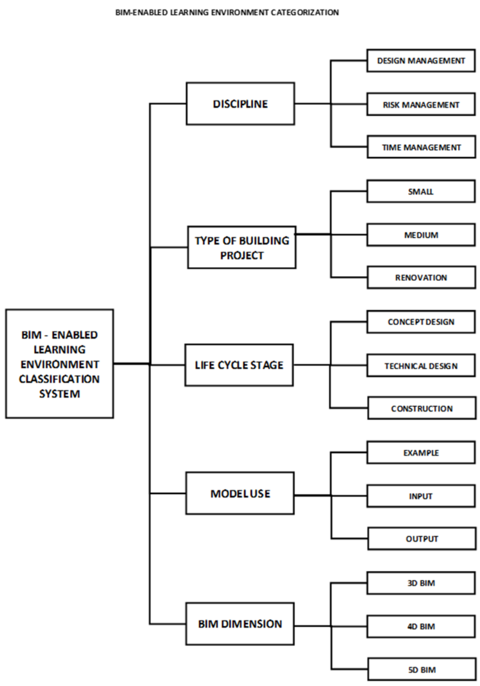

Fig. 9: BIM-enabled Learning Environment (BLE) categorization.

5. ACKNOWLEGMENTS

This research was supported by the BIM-enabled Learning Environment for Digital Construction (BENEDICT) project (grant number: 2020-1-EE01-KA203-077993), co-funded by the Erasmus+ Programme of the European Union. The European Commission support to produce this publication does not constitute an endorsement of the contents which reflect the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

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ISSN 2704-601X (print)
ISSN 2704-5846 (online)
ISBN 979-12-215-0289-3 (PDF)
ISBN 979-12-215-0257-2 (XML)
DOI 10.36253/979-12-215-0289-3
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