D4.3 CinderOSS BIM Library module

September 2020 (M28)

Responsible partner: **BEXEL**

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 776751

Document Details

Title:	CinderOSS BIM Library Module
Annexes:	3

Deliverable No.	4.3
Work Package:	4
Task:	4.4
Deliverable Type:	Other
Lead Partner:	BEXEL
Contributing Partner(s):	KplusV, ZAG, UB, Opencontent, FGP, TECNALIA, NIGRAD, IETU, AEDHE, TUDelft, POLO PN, CEIM
Due date of deliverable:	16th of October 2020
Actual submission date:	16th of October 2020

Dissemination level:		
PU	Public	X
RE	Restricted to a group specified by the consortium (including Commission Services)	
CO	Confidential, only for members of the consortium (including Commission Services)	

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 776751

EXECUTIVE SUMMARY

Building Information Modelling (BIM) has become established as an invaluable process enabler for modern architecture, engineering, and construction (AEC), facilitating stakeholder communication, information collection and exchange, improving the quality of design solutions, and overall efficiency in construction projects, through the optimisation of time and resources, the reduction of misunderstandings in time and spatial conflicts, and unnecessary repetitive tasks.[1] Correspondingly, to demonstrate the benefits of a modern IT-driven approach, the CINDERELA BIM two-stage implementation strategy has been established, firstly, at the project level and running in parallel with the secondary raw material (SRM)-based solutions (product level), both being closely related and both directed towards waste reduction and support and promotion of the project sustainability goals.

The deliverable is primarily focused on the product level, and represents the textual part of project deliverable D4.3, complementing the results provided in the form of the BIM Library – the information database, structured and corresponding with the BIM objects developed in the Industry Foundation Classes (IFC) openBIM file format (ISO 16739). This will all be used to populate the CINDERELA One-Stop-Shop BIM Library module with the goal of diffusion of the SRM-based construction products which are being developed within CINDERELA.

The document also presents the CINDERELA approach for addressing the above-mentioned BIM Library challenges by developing a standardised properties dataset that promotes circularity and environmental indicators of innovative construction products. The workflow of library development is explained, and examples of the BIM Library objects are shown.

Following this path, the CINDERELA project is promoting circular economy business models that include the development of SRM-based materials and their laboratory and real-life testing in CINDERELA demonstration cases. Furthermore, the CINDERELA One-Stop-Shop (CinderOSS) platform is being developed to share and promote the collected knowledge and will include the BIM Library module to complement its production and construction section.

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Keywords:
Building information modelling, library, circular economy, one stop shop, environmental footprint

[1] Eastman, C., Sacks, R., Lee, G., & Teicholz, P., BIM Handbook: A Guide to Building Information Modeling for Owners, Designers, Engineers, Contractors, and Facility Managers (3rd ed.), New Jersey: Wiley, 2018

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EXPLANATION OF ACRONYMS & ABBREVIATIONS

Acronym	Full name
AEC	Architecture, Engineering & Construction
AEDHE	ASOCIACION DE EMPRESARIOS DEL HENARES
BEXEL	BEXEL CONSULTING DOO BEOGRAD
BIM	Building Information Modelling
CDE	Common Data Environment
CEIM	Civil Engineering Institute Macedonia - CEIM
CinderCEBM	CINDERELA Circular Economy Business Model
CinderOSS	CINDERELA One-Stop-Shop
COBie	Construction Operations Building Information Exchange
D	Deliverable
EC	European Commission
ETU	INSTYTUT EKOLOGII TERENOW UPRZEMYSLOWIONYCH
FGP	Fundación Gómez Pardo
GUID	Globally Unique Identifier
H2020	Horizon 2020 The EU Framework Programme for Research and Innovation
ICT	Information and communications technology
IFC	Industry Foundation Classes
ISO	International Organization for Standardization
KplusV	KplusV organisatieadvies B.V.
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
M	Project month (e.g. M6 stands for month 6 of the project)
NBS	National Building Specification
NIGRAD	NIGRAD d.d. komunalno podjetje
OP	Opencontent SCARL
POLO PN	POLO TECNOLOGICO DI PORDENONE SOCIETA CONSORTILE PER AZIONI
S-LCA	Social Life Cycle Assessment
SRM	Secondary raw material
TECNALIA	FUNDACION TECNALIA RESEARCH & INNOVATION
TUDelft	TECHNISCHE UNIVERSITEIT DELFT
UB	UNIVERSITA COMMERCIALE LUIGI BOCCONI
WP	Work package
ZAG	ZAVOD ZA GRADBENISTVO SLOVENIJE

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 776751

Document history

Version	Date	Partner	Author	Changes
1	04/3/2020	BEXEL, ZAG	Igor Osmokrovic, Sebastjan Meza	Document creation
2	16/3/2020	UB, TECHNALIA	Matteo Donelli, Ainara Garcia Uriarte	Supplementing on environmental indicators
3	08/9/2020	BEXEL	Igor Osmokrovic	Initial draft
4	14/9/2020	BEXEL, ZAG	Igor Osmokrovic, Sebastjan Meza	Revision, discussion
5	17/9/2020	BEXEL, Opencontent, ZAG	Igor Osmokrovic, Simona Zelli, Lorenzo Salvadorini, Sebastjan Meza	Revision of CinderOSS BIM platform functionalities
6	22/9/2020	BEXEL	Igor Osmokrovic	Writing complete version. Sharing with CINDERELA partners
7	25/9/2020	KplusV, ZAG, UB, FGP, CEIM	Douwe Huitema, Sebastjan Meza, Matteo Donelli, Dobriela Rogozareva, Lidia Gullon	Revision, supplementing
8	30/9/2020	BEXEL	Igor Osmokrovic	Document finalisation
9	9/10/2020	ZAG	Katja Malovrh Rebec	Independent BIM expert review
10	16/10/2020	Professional proofreading service	/	proofreading
11	16/10/2020	ZAG	Sebastjan Meža	Final quality check

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1. INTRODUCTION

Comprehensive adoption of BIM is changing the way information is being managed in the Architecture, Engineering and Construction (AEC) industry.[2] Likewise, it facilitates stakeholder communication, information collection and transmission, improving the quality of design solutions, and overall efficiency in construction projects, through the reduction of time and resources due to rework, misunderstandings, time and spatial conflicts, and unnecessary repetitive tasks.[3]

The BIM methodology is based on the Building Information Model (BIM) that provides a representation of the design facility made from BIM objects carrying detailed information and quantitative properties used for various analyses throughout the entire project life cycle. Further on, the BIM model consists of BIM objects that are collected in BIM families. BIM libraries form an online repository of BIM objects that are used by designers in the process of BIM design development. In this way, products are implemented in the project design, which is why BIM libraries have an important role in product dissemination.[4] This potential has been recognised by multiple researchers, as well as by the product manufacturers who are the main contributors to BIM libraries. Data inconsistency among BIM objects makes product comparison difficult, while software-dependent BIM objects have limited potential in product dissemination.

1.1. Deliverable in the context of CINDERELA project

Among others, the CINDERELA objectives include promotion of the circular economy, its goals and processes in AEC, as well as developing a circular economy business model (CinderCEBM) for the use of secondary raw materials (SRM) in urban areas. The central place for on-line marketing and sharing of collected knowledge is an on-line ICT platform called the CINDERELA One-Stop-Shop (CinderOSS) (Figure 1). CinderOSS aims to attract a wide range of construction stakeholders, and provide various functions and a vast knowledge database divided into five modules: Digital Business Ecosystem; Production & Construction, CinderCEBM, Research & Development, and Market & Legislation.

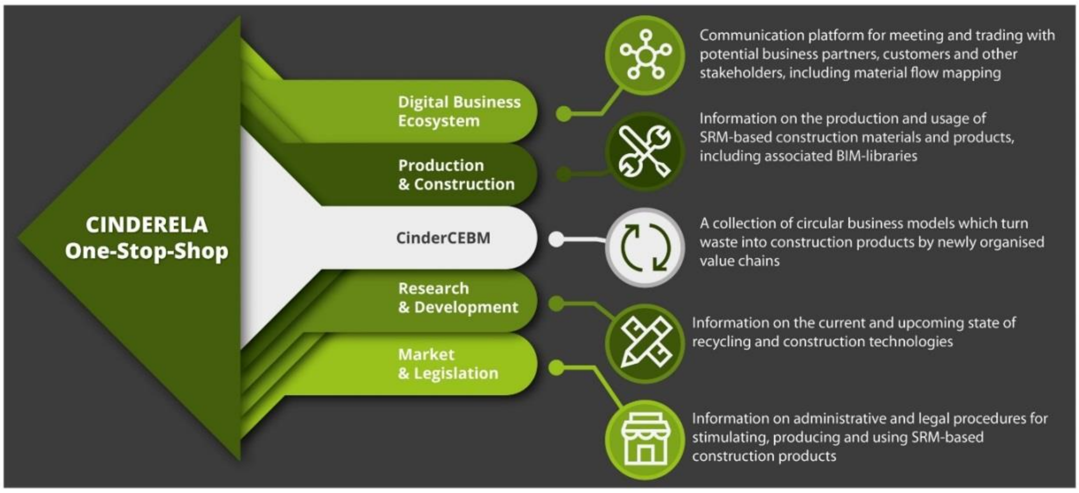

Figure 1 CINDERELA One-Stop-Shop Schema

[2] Rimmington, A., Dickens, G., & Pasquire, C., "Impact of Information and Communication Technology (ICT) on construction projects," Organization, Technology and Management in Construction: an International Journal.
[3] Eastman, C., Sacks, R., Lee, G., & Teicholz, P., BIM Handbook: A Guide to Building Information Modeling for Owners, Designers, Engineers, Contractors, and Facility Managers (3rd ed.), New Jersey: Wiley, 2018
[4] https://www.thenbs.com/knowledge/exploring-the-nbs-bim-object-standard

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Within the CINDERELA project, SRM-based construction products are being developed, tested and implemented in real construction demonstration projects. Additionally, their environmental, economic and social aspects of sustainability are being verified. To support the listed actions, BIM is being implemented in the design development phase of selected CINDERELA demonstration projects, and will be carried on also during planning and tracking of construction progress, as well as for facility management. Therefore, the information database already developed for the design solutions will be further updated and compared with real construction data, and will serve as a reliable source of information for various analyses, as well as for the planning and estimation of the operational costs of built facilities.

In parallel with BIM model development, the most important sustainability properties of SRM-based construction products are defined, and are to be included in the BIM model to promote the circular nature of the components used through the extraction of the library of BIM objects serving as a template for future reuse of the same products.

This document presents the structure of the developed BIM library, the property structure found to be relevant for the CINDERELA goals, and further use of BIM objects. Also, it provides the planned structure of the BIM library module within the CinderOSS that will be populated with the BIM objects created. It explains the interactions within the CinderOSS Library module during the CINDERELA project as well as the suggested transformation of the interactions chart upon project completion.

1.2. Relation to the Work Packages

Aside from the deliverables and tasks within WP4, directed towards the implementation and publication of the CinderOSS BIM Library module, the information management that is the very core of BIM methods and processes implies that this deliverable is closely related to multiple project Work Packages (WP).

The deliverable is in direct connection with WP 5 - Designing, development and testing of SRM-based construction products for demonstration pilots, since the BIM objects that constitute the initial BIM library collection are being developed during the BIM model development process in the design development phase of the demonstration cases within Task 5.4 - Detailed plan for technological pilot demonstrations. Beside the extracted BIM library, BIM models developed within Task 5.4 were used for various 3D/4D/5D BIM analyses, significantly contributing to the construction of the demonstration cases planned within WP 6. Also, it has been developed to include the designed SRM-based products and to reflect the current findings and examinations of Task 5.1, while allowing further improvement of objects' metadata by synchronisation with the technical information database, based upon which the testing of materials and products is finalised.

Furthermore, the BIM objects provide the basis for bi-directional data exchange with WP 7: Monitoring and sustainability of CinderCEBM. The BIM models seek to provide quantifications as an input for the Life Cycle Assessment (LCA) and Life Cycle Costing (LCC), while the BIM objects will include the selected product environmental indicator properties, which are the results of LCA, LCC and S-LCA analysis, in order to provide complete and reusable information for the designed, developed and tested SRM-based construction products.

In WP 6: Pilot demonstrations of SRM-based construction and testing of CinderCEBM, BIM models and analysis developed using initial BIM objects are used for detailed 4D/5D planning and monitoring of construction progress, while the real project data and material characteristics and costs are collected. Finally, sensors will be built in selected elements of the demonstration projects, and the BIM objects will allow the integration of sensor data in order to track the behaviour and long-term response of the developed products and materials.

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2. BUILDING INFORMATION MODELLING

2.1. BIM Methodology

BIM is a collaborative work methodology which has gained great importance in the AEC industry. The traditional approach to building design, construction and maintenance has been significantly changed with the adoption of BIM methodology that integrates all phases of the construction process, connects people, promotes collaboration, process-automation and data management, and enables transparent transfer of information and communication[5] (Figure 2).

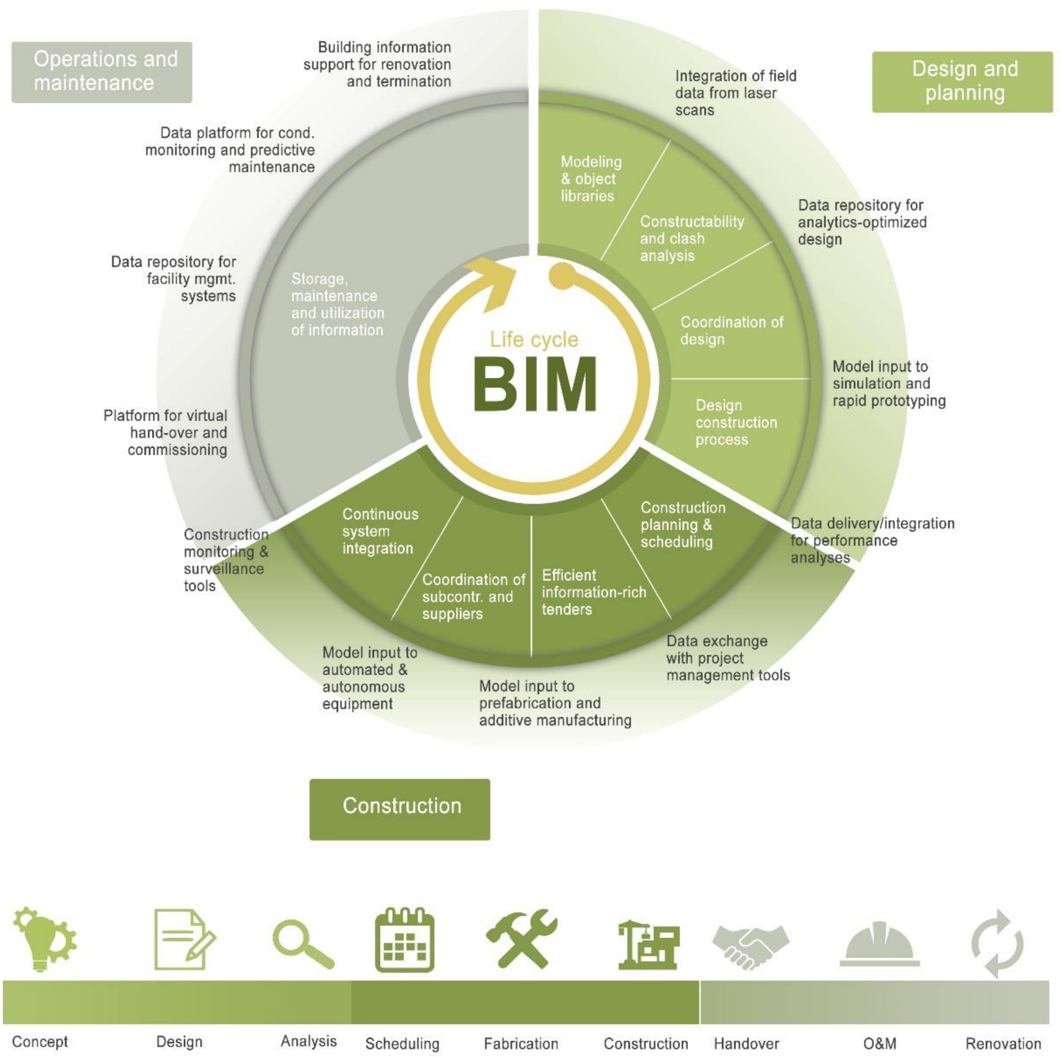

Figure 2 Life Cycle BIM
Adapted from Cemex Ventures[6]

[5] Eastman, C., Sacks, R., Lee, G., & Teicholz, P., BIM Handbook: A Guide to Building Information Modeling for Owners, Designers, Engineers, Contractors, and Facility Managers (3rd ed.), New Jersey: Wiley, 2018
[6]https://www.cemexventures.com/discover-how-bim-is-implemented-in-each-phase-of-the-construction-industry/

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The BIM methodology seeks to integrate the processes and professionals involved in the entire building life cycle by working on platforms with coordinated and intelligent BIM models. In a building or infrastructure project, the most important thing is to understand the objectives, vision and mission of the project, take advantage of available resources and generate the most suitable plan to fulfil the project goal. Since BIM methodology is dedicated to the reduction and management of waste in the construction industry, BIM's involvement in the CINDERELA project begins with the development of demonstration BIM models and BIM families in openBIM format with all relevant information available to all interested parties.

2.2. BIM standards and guidelines

Various studies show that although BIM has been available for more than two decades, the implementation of BIM in everyday practice still has the potential to be improved. There are various factors that hinder the process and among them the lack of standardisation is an important one;[7] therefore, to reach a global understanding, improved implementation and also to avoid disjointed approaches, standardisation on a global scale is crucial.

Standardisation efforts on a global scale work towards BIM becoming the future driver in international projects and have already resulted in the establishment of the Industry Foundation Classes (IFC), International Standards (ISO), National and Global BIM Product Databases and Libraries.

IFC is the standard for open BIM data exchange (ISO 16739-1:2018) which enables and encourages interoperability. Using IFC in the CINDERELA project aims to enable construction professionals to use the CinderOSS BIM Library in their projects, unrelated to specific software. Construction professionals can use the software application of their choosing to work with data. IFC is supported by 150 software applications worldwide and this kind of interoperability is crucial as the AEC industry becomes increasingly collaborative.

In addition to the above-mentioned ISO standard, it is crucial to mention some of the other ISO standards we have followed through the path of successful BIM implementation on the CINDERELA project:

ISO 16739-1:2018 – Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries — Part 1: Data schema

ISO 19650-1:2018 – Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM)

ISO 19650-2:2018 – Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling — Part 2: Delivery phase of the assets

ISO 19650-3:2020 – Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling — Part 3: Operational phase of the assets

ISO 19650-5:2020 – Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling — Part 5: Security-minded approach to information management

ISO 23386:2020 – Building information modelling and other digital processes used in construction - Methodology to describe, author and maintain properties in interconnected data dictionaries

ISO 12006-2:2015 – Building construction - Organization of information about construction works— Part 2: Framework for classification

[7] Poljanšek, M. (2017). Building Information Modelling (BIM) standardization. ISBN 978-92-79-77206-1: European Commission.

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ISO 12006-3:2007 – Building construction - Organization of information about construction works — Part 3: Framework for object-oriented information

ISO 21597-1:2020 – Information container for linked document delivery - Exchange specification — Part 1: Container

ISO 29481-1:2016 – Building information models — Information delivery manual — Part 1: Methodology and format

ISO 14040:2006 – Environmental management - Life cycle assessment - Principles and framework

ISO 23387:2020 – Building information modelling (BIM) — Data templates for construction objects used in the life cycle of built assets — Concepts and principles

ISO 15686-5:2017 – Buildings and constructed assets — Service life planning — Part 5: Life-cycle costing

2.3. Collaboration and information exchange. Open BIM

Transforming the processes of design, building and the use of building and infrastructure assets in the era of information technology enables the AEC industry to expand this transformation through interoperability and collaborative BIM-based processes. An open, flexible, demand-driven, interactive environment is the future of the AEC industry, so the future supply chain will require any and all stakeholders to use, manage and utilise digital information.

As a single source of truth, the CDE can serve as an ultimate source of information and brings a number of advantages for all participants involved (Figure 2). The reduced time and cost of producing coordinated information, connecting teams, BIM models and project data in one environment are just some of the benefits that CDE brings to its users. Advanced BIM-based CDE systems integrate all kinds of project information, as shown in Figure 3 in an example of the BEXEL Manager platform used in CINDERELA.

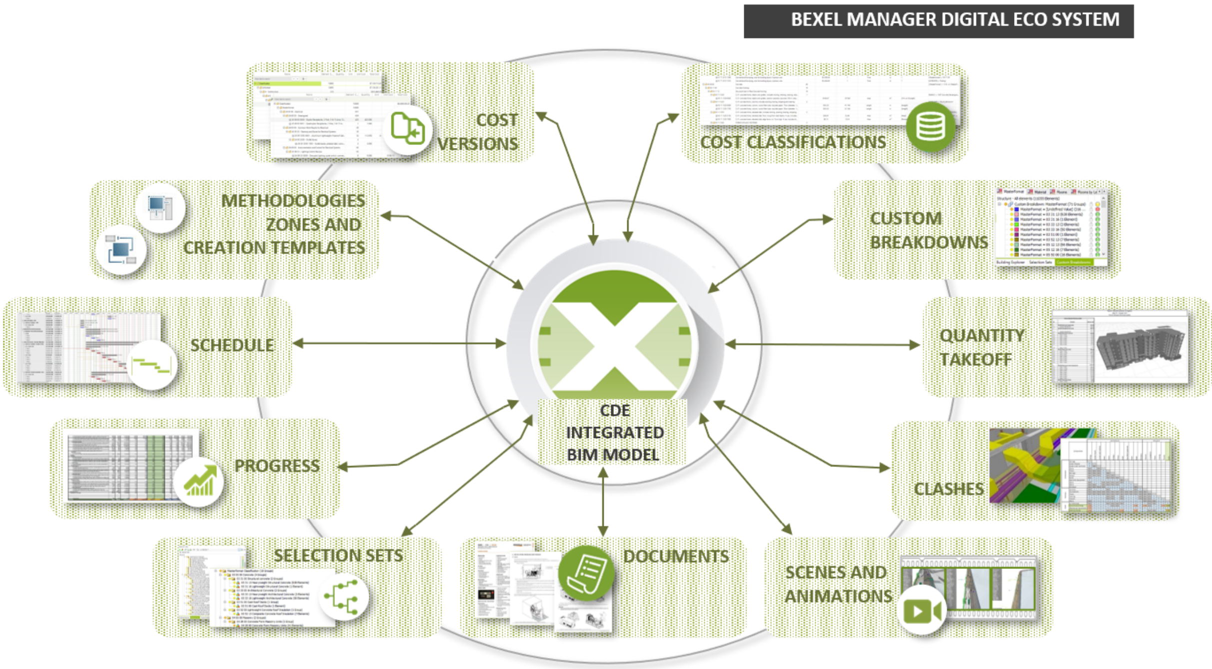

Figure 3 CDE – Common Data Environment scheme

OpenBIM extends all these benefits on a higher level by improving the accessibility, usability, management and sustainability of digital data in AEC. With openBIM, an AEC company can select tools depending upon the individual requirements of a project, while still using all the benefits of

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model-based collaboration. In addition, we can say that openBIM establishes a common language for worldwide referenced projects and processes, reducing coordination errors and misunderstandings between all project stakeholders.

In line with the CINDERELA approach, openBIM is used to maintain collaboration between all future users of the CinderOSS BIM Library by providing them with the possibility to get acquainted with the content of the CinderOSS BIM Library through a vendor-neutral collaborative process.

2.4. BIM Analyses

During the life cycle of a project, the BIM model can be used for various analyses (Figure 4) which can bring great benefits to all project stakeholders.

DESIGN	BUDGETING	TENDERING	CONSTRUCTION PLANNING	CONSTRUCTION	OPERATION
• Design Review • Clash detection	• QTOs • BOQs • Project budget development	• QTOs • Preparation of tender packages	• 4D/5D construction planning • Creation of construction schedule • Resources allocation histograms • 5D Cash flow analysis • Optimization of construction schedule •LOB	• Interim payment certificates • 4D/5D Progress tracking • Planned/Actual • Procurement planning • Claim management	• Commissioning • As-Built BIM Model • 6D BIM Facility Management

Figure 4 BIM analyses

The BIM model collects dynamic and fragmented data together and enables BIM-based life cycle information management. Analyses through the building life cycle include analysis in the design, budgeting, tendering, construction planning, construction and operation phases.

The section below describes all relevant BIM analyses separated by the phases that are usually performed from a BIM model, and Figure 5 shows the frequency of their implementation in the AEC industry:

1. DESIGN
    - *Design review* – the process according to the predefined procedure in the BIM Execution Plan in which a 3D model is analysed by stakeholders to validate multiple design aspects.
    - *Clash detection* – the BIM technique to identify where two parts of the reviewed project are intersecting with one another.
2. BUDGETING
    - *Quantity takeoffs* – detailed measurement of building element quantities per predefined breakdown structure of the project.
    - *Bill of quantities* – detailed item descriptions with defined prices, dimensions, units, materials, quantities for tendering purposes.
    - *Project budget development* – using BIM models for a cost review of as many different options as possible to facilitate decision making and budget development in the BIM environment.
3. TENDERING
    - *4D/5D construction planning* – advanced planning techniques that integrate schedules and budgets and allow stakeholders to efficiently analyse projects according to time and cost.
    - *Creation of construction schedules* – integration of 3D building components and time and automatic creation of detailed schedules.
    - *Resource allocation histograms* – managing construction site resourcing in the most efficient way by identifying critical paths when activities can be performed and resource needed for competition.
    - *5D cash flow analysis* – describes a balance between basic financial inputs and outputs in

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and out of the proposed project, supporting further advanced analysis such as NPV, IRR, ROI.

- *Optimisation of construction schedule* – analysis of construction schedules in terms of ordering and prioritising tasks appropriately to reach near-optimal usage of labour and equipment resources.
- *Line of balance (LOB)* – a management control process represented by a flowline diagram according to which the automatically generated schedule is optimised.

4. CONSTRUCTION

- *Interim payment certificates* – monitoring that the payment requests of contractors genuinely reflect the quantity and quality of work performed on the construction site.
- *4D/5D progress tracking* – regularly maintaining construction progress through the 4D/5D BIM model and identifying setbacks or pitfalls arising from poor scheduling, resource under-allocation, or other.
- *Planned/actual analysis* – comparative analytics of initial construction schedule and construction works carried out up to specific date.
- *Procurement planning* – process for maintaining satisfactory construction tempo and preventing delays arising from lack of materials or equipment on the construction site.
- *Claim management* – process for controlling contractual rules automatically and consistently during the project through the BIM model as an integrated repository of all relevant information.

5. OPERATION

- *Commissioning* – process of ensuring that a building fulfils its stated function through BIM tools as a document repository.
- *As-built BIM model* – includes capturing alterations from construction documents in an easily accessible manner, being a source for future building maintenance and procurement planning, and providing a snapshot of the existing design.
- *6D BIM facility management* – centralised, model-based 6D facility maintenance planning and tracking, containing equipment data, documents, specifications and materials.

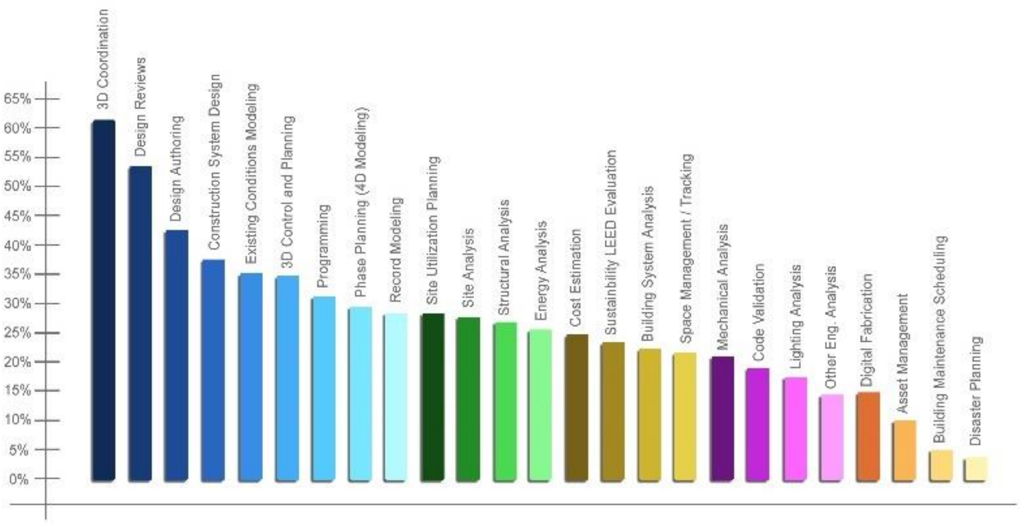

Figure 5 Bar chart of the frequency of use of each BIM use
Adapted from https://buildinginformationmanagement.wordpress.com/tag/omniclass/

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2.5. BIM AND CIRCULAR ECONOMY

2.5.1 BIM AND LIFE CYCLE THINKING

The global consumption of non-renewable resources, a growing shortage of primary raw materials, and insufficient space for waste storage are primary reasons why waste and resource management is becoming a very important concern. One of the main strategies to minimise environmental impacts and the energy consumption is by maximising recycling rates.[8] BIM as a container of all material information in the form of a digital platform for the life cycle management of buildings and material resources can significantly assist in setting strategies to reduce the environmental impact and energy consumption with a significant increase in recycling rates.

The general approach in the CINDERELA project aims to develop an international CinderOSS BIM Library with standardisation of secondary raw materials recovered from waste streams, setting up new waste-to-products flows supported by:

- Life Cycle Assessment (LCA)
- Life Cycle Costs (LCC)
- Social Life Cycle Assessment (S-LCA)

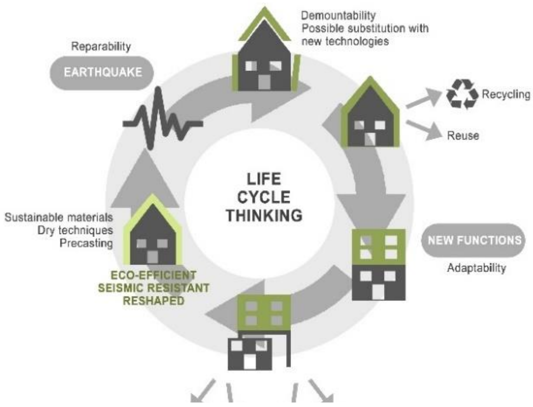

Figure 6 Life cycle thinking

Adapted from source:
Life Cycle design for Sustainability and Resilience targets

2.5.2 BIM AND LCA

Current environmental problems arising from AEC require tools to help reduce resource consumption and environmental impacts. One way to improve and optimise the environmental performance of buildings as well as their sub-components in the planning phase is Life Cycle Assessment (LCA).[1] BIM as a quality control tool and the material container can significantly simplify the process of LCA analysis for construction projects.

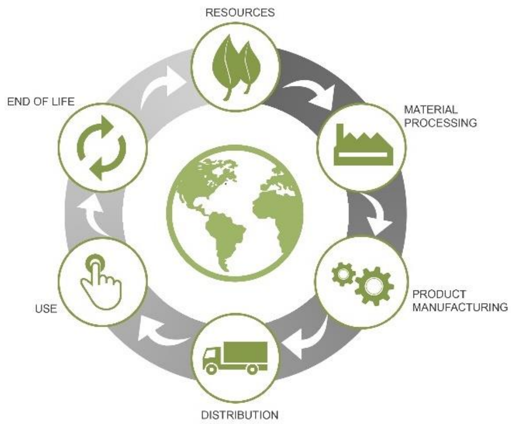

Figure 7 Life Cycle Assessment

Adapted from M.L. Brusseau, in Environmental and Pollution Science (3rd ed.), 2019

Life Cycle Assessment (LCA) is a widely used tool for quantifying the environmental impact of the construction sector. For LCA analysis a crucial factor is detailed information about material composition, which can be delivered most accurately within the BIM software platform. CinderCEBM will be assessed using a life cycle approach including LCA and related methods such as Social LCA and Life Cycle Costing to drive business improvement in terms of environmental, social and economic aspects at all stages of the life cycle of SRM-based construction projects. The CINDERELA project aims to find a balance between environmental, social and economic aspects. Integration with important tools like BIM and LCA enables a wider approach to sustainability to become possible and to deliver a successful project on time, on budget, and with the use of SRM with a low environmental footprint.

[8] Honic, M., Kovacic, I., Sibenik, G., & Rechberger, H. (2019). Data-and stakeholder management framework for the implementation of BIM-based Material Passports. *Journal of Building Engineering*, *23*, 341-350.

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2.5.3 BIM AND LCC

Life cycle costing (LCC) is the optimal methodology for increasing the savings of a building or infrastructure project by comparing several different design alternatives. The LCC is based on long-term costs and savings that are interconnected throughout the life cycle of a facility by estimating all costs starting from construction, through maintenance, operation and end-of-life costs of the facility. Further, in the CINDERELA project, environmental externalities will be included in the life cycle costs related to a construction work. Environmental externalities refer to the economic concept of the uncompensated environmental effects of production and consumption that affect the consumer utility and enterprise cost, outside the market mechanism (Source: CINDERELA Deliverable 7.2).

Life cycle cost analysis (LCCA) represents financial analyses through all phases of a construction project in order to achieve the optimal option with the highest investment return by comparing different design solutions. LCA, LCC and LCCA are methodologies that are usually conducted together and bring multiple benefits to the project.

Figure 8 Life Cycle cost
Source: CINDERELA

The integration of BIM with life cycle assessment (LCA) and life cycle costing (LCC) will represent a step toward environmental integration and the most efficient means of material comparison. The proposed framework for BIM-LCA/LCC analysis starts with the automatic identification of the elements and materials in the project, as well as quantities, where the required LCA and LCC parameters are inserted in the BIM work environment. After entering the required environmental and economic indicators, the BIM model can be exported in openBIM format (IFC). As these parameters are not currently fully defined in the IFC scheme, the parameters can be manually set for export for all relevant data. The benefit of this approach and the enrichment of BIM models with LCA and LCC parameters, as well as their export in an open format, is that the user can view, edit and use all information from an integrated BIM-LCA/LCC model in other BIM software. Another great advantage of this integrated approach is reflected in material changes and LCA/LCC indicators, where users can enter information changes directly into the BIM model or in the appropriate BIM family and automatically obtain new material specifications that can be used for further analysis. This approach for a specific organisation means that they will get an appropriate BIM library with LCA and LCC indicators, which can later be used for analysis of other similar projects at an early stage of project design. Further development of this integration would ensure that manufacturers already have LCA/LCC indicators implemented in their BIM families, leaving space for designers to add some of the individual data related to a specific project and thus significantly save time and information loss.

In terms of asset management utilising LCC analysis, stakeholders are focused on defining decision criteria to achieve company objectives through the control of life cycle activities of assets. Asset management helps to determine how, where, and when to spend your limited money. It is about maintaining a desired level of service at the lowest appropriate life cycle cost. The life cycle cost represents the total cost of ownership of an asset: the purchase price, the cost of operating and maintaining it, refurbishments, and final disposal. All this, in synergy with the LCC methodology, brings value-orientated decision support into asset management decision-making processes.

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2.5.4 BIM AND S-LCA

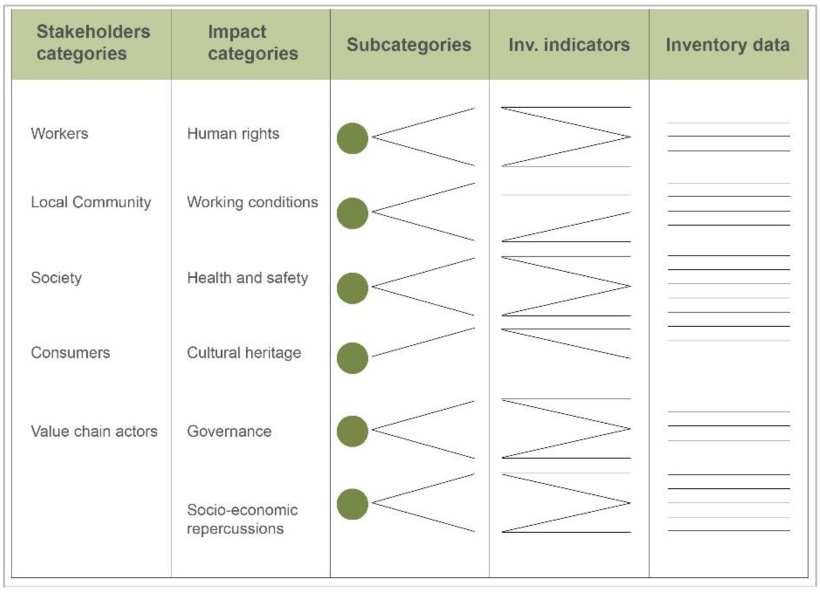

Figure 9 Social LCA framework

Source: M.L. Brusseau, in Environmental and Pollution Science (3rd ed.), 2019

Social life cycle assessment (S-LCA) is a methodology that can be used to evaluate the social aspects of products, their positive and negative impacts during the life cycle. S-LCA is mostly related to the raw material extraction and manufacturing industry, production, distribution, use, reuse, maintenance, recycling and final disposal. This method complements the LCA and LCC environmental methodology and uses location-specific data, but does not provide an answer to the question of whether a product should be produced or not, but only sets guidelines for making the final decision. The ultimate goal of using S-LCA is to promote the improvement of social conditions and the overall socio-economic performance of the product during its life cycle for all its stakeholders.

The combination of LCA, LCC and S-LCA will provide the CINDERELA project with a necessary tool for assessing product sustainability. The sustainability of the CinderCEBM business model will be based on environmental, economic and social assessment throughout the project life cycle. The environmental performance of the SRM-based construction materials will be assessed using the Environmental Technology Verification (ETV) scheme.

Figure 10 Tools to assess sustainability within CINDERELA project (Source: CINDERELA Deliverable 7.2)

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2.5.5 BIM FOR DISASSEMBLY

2.5.5.1 Maintenance planning, better maintenance, better disassembly

Maintenance is an important segment of the AEC project life cycle. Therefore the focus not only on the construction, but also on the delivery of sustainable and efficient facilities leads to the need for comprehensive, detailed, and indispensable analyses of facility maintenance at the earliest stage of the project life cycle. In order to reduce the budget for the maintenance of a building or infrastructure project, project stakeholders must approach maintenance planning as one of the most important tasks for the handover of sustainable and successful projects. Consequently, the quality of maintenance planning reflects enormously on the quality of dismantling the facility at the end of the life cycle.

Disassembly Network Analysis (DNA), working together with BIM, aims to deliver information about recovered and lost materials and the time needed for disassembly. CinderOSS aims to detect potential points of improvements regarding waste generation and the time needed to disassemble an element. In the CinderOSS BIM library additional metadata will be stored in BIM objects, such as the type of object and their location.

All materials implemented in a building and used in AEC have their value. By enabling circular AEC in which used materials can be reused after demolition of the building, we are creating a sustainable future. Thanks to this visionary idea, the door has been opened to great projects that are pushing the construction sector towards a circular economy. Below are briefly described some of these great projects, such as BAMB,[9] MADASTER[10] and CIRKELSTAD,[11] which together with the CINDERELA project aim to achieve a common goal – waste-to-resource opportunities.

The BAMB project aims to utilise the true value of materials to enable a circular building industry. BAMB based its project on the reverse thinking that buildings are made of components that are easy to replace, transport, dismantle and reuse while avoiding waste. The idea of a Material Passport that will contain information on all the materials used to construct a building must be based on a change in the design culture of the project that will support the future reuse of the building and its components.

The MADASTER project represents a web library of materials in a constructed environment and provides materials with an identity in the form of a material passport. The benefit of using a material passport is reflected in obtaining information about the materials and quantities used in a particular facility. The MADASTER platform also enables the uploading of the BIM model in the open IFC format as a source of information and the basis for the project for which we want to generate a material passport. The platform also allows the use of a 3D model viewer so that users can virtually navigate through the building and see where materials and products are located.

Another interesting concept that changes the way of thinking about the material life cycle was presented through the cradle-to-cradle methodology. The cradle-to-cradle (C2C) concept is based on the infinite circulation of materials in cycles that attempts to follow the regenerative cycle of nature in which waste is reused.

[9] https://www.bamb2020.eu/
[10] https://www.madaster.com/en
[11] https://cirkelstad.gses-system.com/

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3. CINDERELA BIM ROADMAP

The CINDERELA project has incorporated a comprehensive BIM workflow that integrates the entire life cycle of the project, starting from design development, information management, execution planning and monitoring, as well as facility maintenance management. The BIM implementation roadmap includes four major steps that are aligned with the project development phases:

- For the earliest design phases, BIM models for all three CINDERELA pilot demonstrations taking place in Maribor, Skopje and Madrid were developed based on 2D and 3D design documentation. The models are developed using the Revit[12] or Civil3D[13] authoring tools, and model federation has been done with the BEXEL Manager[14] platform. This enabled a thorough analysis of the design solution that was discussed with the design team to clarify the design intention from the earliest stages of design development.
- The second step includes the augmentation of the BIM objects information with an agreed CinderOSS BIM Library properties set. Also, the database structure and BEXEL Manager platform Add-in has been developed for automated and simple synchronisation of the actual property values as they appear within the related CINDERELA tasks. Further, in the planning stage of the demonstration projects, the BEXEL Manager platform was used to develop analyses such as quantity takeoffs, the work breakdown structure and 4D (time)/5D (cost) schedule estimation.
- The third step refers to project execution tracking within the BIM model. In this stage, a lot of information will become available, and the CinderOSS BIM Library property dataset will be populated with additional data. Monitoring of project execution in the BIM environment will include progress reports, and planned vs actual analyses. Finally, during project execution, the BIM models will be updated with the project changes made and approved on site. Managing all the data listed above will result in a so-called as-built model. Also, since innovative materials are implemented, some building elements will be equipped with sensors to monitor the real response of the built elements. The intention is to integrate the sensor readings with the BIM model dataset, where CINDERELA is planning to collaborate with another EU-funded project called Assets4Rail.[15]
- Finally, the BIM models will be further improved with the linking of the collected as-built documentation, and creating long-term facility maintenance plans with defined maintenance activities, recurring periods and estimated costs. Correspondingly, the operational costs of the facility will be estimated. In that phase, final attributes will be added to the properties database, and the BIM library exported and uploaded to the CinderOSS BIM Library module. Further use of the BIM model during the operation phase by the facility owner is possible, and would include regular inputs of the maintenance activities conducted to create a valuable database for consideration of the reusability of the building elements at the end of the life cycle. Here it should be mentioned that such system will provide the facility owner with regular notifications on the required maintenance activities that, implemented on time, will increase the life time of particular building components, which also contributes to overall waste reduction.

In Figure 11, the overall CINDERELA BIM implementation roadmap is shown, while the developed BIM models and analysis are further presented within CINDERELA Deliverable 5.3.

[12] https://www.autodesk.com/products/revit/overview
[13] https://www.autodesk.com/products/civil-3d/overview
[14] https://bexelmanager.com/software/
[15] http://www.assets4rail.eu/

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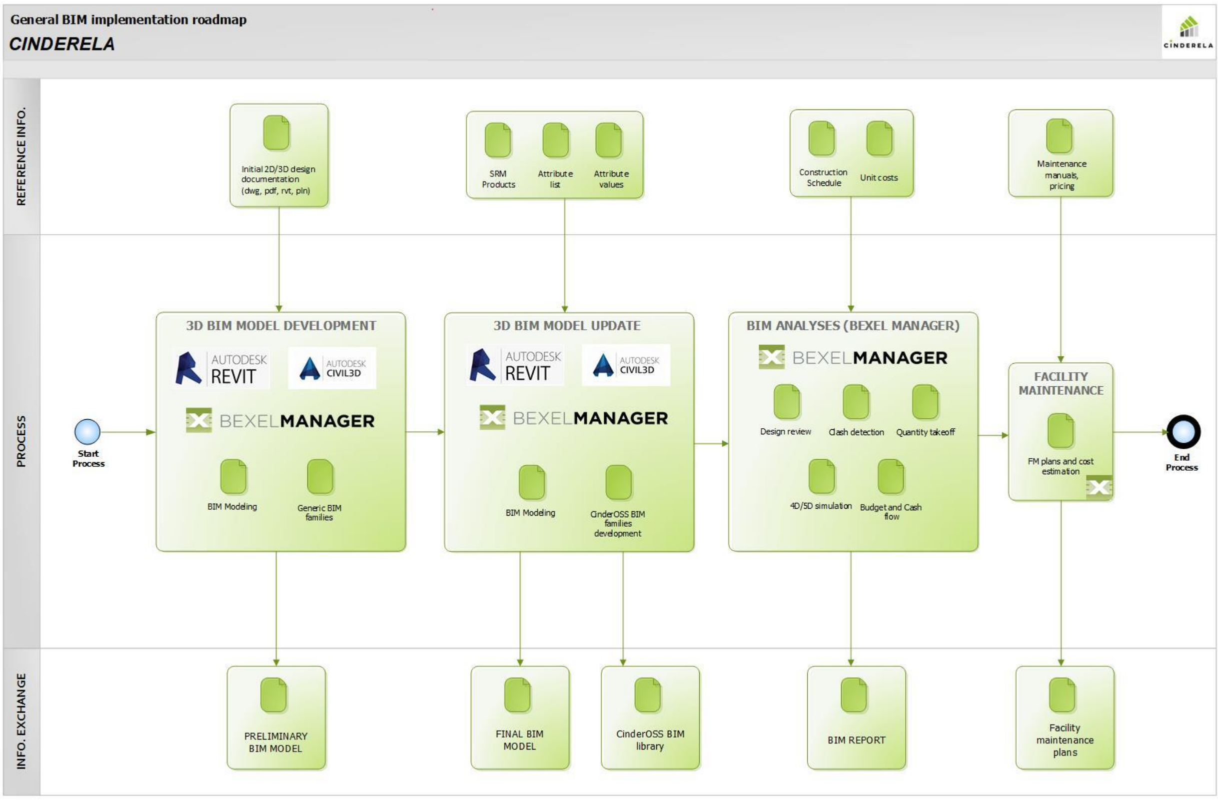

Figure 11 CINDERELA general BIM implementation roadmap

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4. CINDERELA BIM LIBRARY

4.1. BIM Library concept

The efficiency of the BIM model development process can be significantly improved when an appropriate repository of BIM objects is available. By the same token, the usability of the developed BIM model for the following analyses and considerations relies heavily on the quality and consistency of the BIM objects metadata.[16] Therefore, a database of BIM objects representing various construction products and materials is the topic to which great attention in CINDERELA is dedicated.

The BIM model – a data-rich, object-oriented, parametric digital representation of the project, consists of BIM blocks/components in the form of generic BIM objects augmented with relevant data. Considering that the BIM methodology is widespread, especially in the design development phase of the project, BIM libraries nowadays have a central role in disseminating information about innovative products.[17]

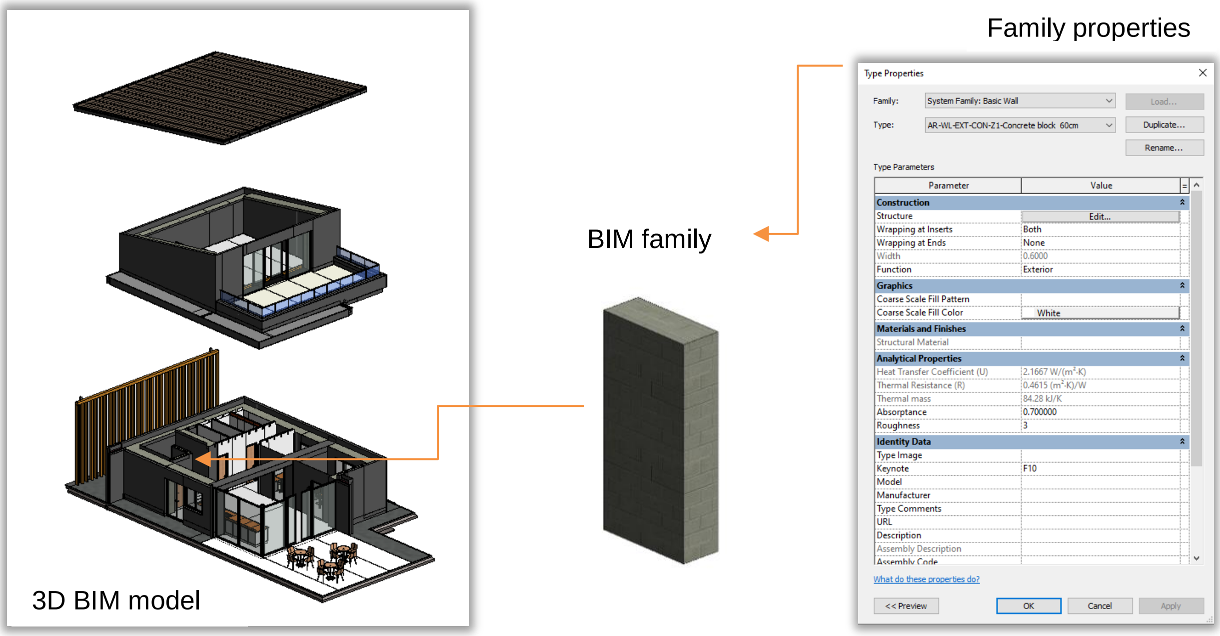

Figure 12 BIM object family and related properties

In CINDERELA, the BIM library is formed as an internet-accessible database containing a repository of product definitions or generic families enriched with relevant metadata; it offers a number of categorisation mechanisms and search facilities for various kinds of users to allow ease of discovery of product definitions.

Three main aspects that define the specific BIM library were identified:

- Platform interface;
- Stakeholders;
- BIM objects.

The platform interface aims to provide adequate categorisation, to search for or compare

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[16] Edirisinghe, R., London, K. (2015). Comparative Analysis of International and National Level BIM Standardization Efforts and BIM adoption, CIB W78 Conference 2015

[17] Bahrami, S., Atkin, B., & Landin, A. (2019). Enabling the diffusion of sustainable product innovations in BIM library platforms. *Journal of Innovation Management*, *7*(4), 106-130.

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mechanisms within the BIM object database and, equally important, it supports stakeholders' interactions and promotion.

The BIM objects have to be quality-checked, certified and compliant with established requirements, and in line with the core goal and specifics of the library itself (promoting innovative products, promoting sustainability, or offering a wide range of manufacturers' BIM objects with technical specifications, etc.). Therefore, semi-automated BIM object quality control algorithms (when new objects are added or existing ones updated) are being developed.

Having BIM objects available in a software-specific file format narrows down the metadata readability, which is why it is preferred to offer BIM objects in the IFC file format according to ISO 16739:2018 and ISO 12006-3:2007 (IFD - International Framework for Dictionaries). IFC is designed to provide the basis for supporting diverse national classification systems and different languages in product libraries. The buildingSMART Data Dictionary (bSDD) is a standard for terminology libraries or ontologies, and for representation of the object classes and their relationships. There are online services offering the open API for the metadata improvement according to the above-mentioned standards such as the buildingSMART bSDD service.

Furthermore, BIM objects based on open data formats with properly organised and consistent information enable integration into different BIM-based designs, procurement and cost engineering applications that bring much-needed help with exchanging and using information from the libraries directly in the design, construction and FM processes.

4.2. Existing BIM libraries

BIM libraries are generally offered by vendor-neutral organisations, by software vendors and by product manufacturers: (1) Widely used BIM libraries are available on vendor-neutral digital platforms such as NBS National BIM library,[18] BIMobject,[19] BIM Store,[20] etc. (2) Repositories are also available at the platforms created by the software vendors: Revit City[21] or BIM Components.[22] (3) Finally, since the most common contributors of BIM libraries are product manufacturers, some of them are offering their own BIM libraries for their own products (Siemens, ABB, Hoermann, etc.).

For a better understanding of the existing ecosystem offering BIM object repositories, some of the well-known BIM libraries are detailed below with a short description of their features and functionalities.

National BIM Library

The National BIM Library is a product of the National Building Specification (NBS) owned by the Royal Institute of British Architects (RIBA) in the UK.[23] The library of products offers users free access to BIM objects. The Library contains objects available in multiple software formats, but the majority of products are available in Revit and IFC file formats. The Library is broken down into more than 150 categories, as well as by the product manufacturer. The platform offers filtering according to the file format, location and discipline. The platform provider offers services of authoring BIM objects or the certification of the BIM objects previously created by the manufacturers. The platform ensures data consistency and the quality of BIM objects through a certification process against the internationally developed and recognised NBS BIM Object Standard (current version 2.1), developed to cope with the lack of structure and consistency across all BIM objects. The above-mentioned document defines

18 https://www.nationalbimlibrary.com/en/find-bim-objects/
19 https://www.bimobject.com/en/product
20 https://www.bimstore.co/search
21 https://www.revitcity.com/downloads.php
22 https://bimcomponents.com/
23 Duddy, K., Beazley, S., Drogemuller, R., & Kiegeland, J. (2013). A platform-independent product library for BIM. In *Proceedings of the 30th CIB W78 international conference*. WQBook.

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general requirements, information requirements, geometry requirements, functional requirements, and metadata requirements for creating BIM objects.

BIMobject

The BIMobject AB is a Swedish innovative company that in 2012 launched the BIMobject Cloud portal, with over 1500 manufacturers offering digital product information. The BIMobject platform has over 1 785 000 registered users and over 450 000 product families, which makes it one of the world's largest libraries for architects, engineers and construction companies that have adopted BIM. The advantage of this platform is reflected in the integration with the software most commonly used in AEC. Users can search through the platform by file types, brands, categories, or regions. BIMobject, apart from free BIM families for users, offers many additional solutions for manufacturers like BIMobject EVO, which helps users to organise their Revit files and is optimised for the Revit workflow. It is worth mentioning also other solutions like Developer API, BIManalytics, and Mosquito, which helps manufacturers not only to create and publish a BIM object but also to use it for analytics and marketing.

The above-mentioned examples of BIM libraries are the most successful ones, with the largest repositories of BIM objects. The National BIM Library dedicates vast attention to information consistency and standardisation of the data structure, yet the differences in the available data between objects are visible. There is a group of properties *NBS_General* that seems to be consistently populated within the majority of objects. Within the BIMobjects repository, data inconsistencies are quite significant. Both libraries provide external links to the product manufacturer's page, or even pdf brochures for more information. The platforms offer different services to users and manufacturers, mainly in terms of BIM object development, certification or analytics. Product sustainability parameters are not found as an emphasised group of parameters in either platform, but the *NBS_Data* property set includes a property called RecycledContent, and also the COBie[24] data set includes the property Sustainability Performance, both of which are arbitrarily filled in the database. While these platforms are good, it is clear that developing a BIM library database focused on the sustainability and circularity indicators of the product would bring something new.

4.3. CINDERELA BIM Library Objective

Multiple researchers show that BIM libraries can foster innovation.[25] Yet there are considerations on how a BIM object's geometry can disseminate the building codes and regulations, and therefore improve the design process, which is far more often recognised in terms of the technical data and information carried within the BIM object. According to researchers, the diffusion of innovation is driven by information dissemination.[26]

The BIM Library that is a part of the CINDERELA project disseminates innovative circular business models and SRM-based products, by capturing results and information from multiple case studies, product development research and analysis, as well as LCA, LCC, and S-LCA results and findings. Therefore, the CINDERELA BIM Library is focused on developing a standardised information dataset for BIM objects.

In terms of CINDERELA, the SRM-based product is considered to be an object or material consisting

[24] https://www.thenbs.com/knowledge/what-is-cobie

[25] Rahimian, F. P., Ibrahim, R., Bridge, C., & Carnemolla, P. (2014). An enabling BIM block library: an online repository to facilitate social inclusion in Australia. *Construction Innovation*.

[26] Frattini, F., Bianchi, M., De Massis, A., & Sikimic, U. (2014). The role of early adopters in the diffusion of new products: Differences between platform and nonplatform innovations. *Journal of Product Innovation Management*, *31*(3), 466–488.

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of a considerable amount of recycled waste. When material is developed with its determined characteristics, it can be used in multiple types of building elements that are implemented in the BIM modelling process using different BIM objects. The CinderOSS BIM Library therefore includes them all as separate BIM objects. For example, the material *green concrete* with its material properties (e.g. compression strength) could be used in elements such as walls, slabs, beams, or columns, which are all separately defined and used in BIM tools.

The CinderOSS BIM Library also includes elements that are refurbished and reused as a whole (e.g. doors, windows, wooden beams, etc.), regardless of the fact that such elements cannot be classified as SRM-based products. Their use promotes the circular goals of the CINDERELA One-Stop-Shop, and can also facilitate the communication between waste brokers, project owners and design consultants, which is one of the main goals of the CinderOSS and its BIM Library as well.

4.4. Data structure and BIM Library development workflow

In order for BIM objects to promote the innovation and the circularity of the SRM products and solutions, a set of properties is defined, which is divided into multiple property sets:

- General product information;
- Location;
- Circular indicators;
- Environmental indicators (LCA);
- Life cycle cost;
- Social life cycle;
- Material properties;
- Sensor monitoring data.

BIM objects in the CinderOSS BIM Library are broken down by General Product Information, primarily object categories, and manufacturers. This approach is regularly found on similar BIM library platforms. Considering that the findings of life cycle analyses are dependent on the location, the location properties are added, and products tagged according to country codes, so the database can be easily filtered based on the location criteria.

For the CinderOSS BIM Library objective, the most important properties within the required dataset are those regarding the circular and environmental impact of the products. This dataset is mandatory for each and every object in the library.

The most relevant environmental impact categories for AEC are selected to be included in the BIM objects, based on the Life Cycle Assessment analyses. These impact categories are included in the EU Product Environmental Footprint Guide.[27] Regarding circularity, the product data includes considerations of: the current scenario – by giving reference to the type and quantity of waste recycled for development of the SRM-based construction product; and the end-of-life cycle scenario – through the recyclability and reusability percentage of the used building element. Similar product indicators are often included in the commercial product ecological certifications and passport within the environmental impact indicator, and the end-of-life recycling rate (PEP ecopassport® Program[28]), or the Circular products catalogues,[29] such as the one developed by Cirkelstad in the Netherlands, and many more.

This approach has been selected in order to align the required data for the CINDERELA BIM Library with EU directives, as well as with material testing and LCA analyses that are already done by a wide

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[27] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32013H0179
[28] http://www.pep-ecopassport.org/pep-association/
[29] https://cirkelstad.gses-system.com/

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range of product manufacturers who are practising the circular approach, for the purpose of different certification programmes. In this way, we ensure that for uploading of their products, manufacturers will not be exposed to any additional cost, and therefore greater growth of the CinderOSS BIM Library repository is expected when the CinderOSS BIM module is published live.

Standardisation of the information dataset, within the collected repository of BIM objects, enables various analyses once they are implemented in the BIM design development process, especially in the early design stages. Within the usual BIM authoring tools there are many difficulties in handling specific material data sets. Also, there are issues with keeping BIM objects up to date with the property database; therefore, another software interface is needed to properly support this process.[30] At the same time, the use of the vendor-independent IFC file format, which allows the accessing, updating and exchanging of parameters, has been the recommended approach.[31] BEXEL Manager, as the BIM project management and analysis tool that allows both import[32] and export of IFC files (versions 2x3, and 4), has been selected since it enables the much-needed flexibility in handling BIM objects' information – adding and editing the information. Moreover, the system has an already established synchronisation of data with Revit objects through the Property Importer Add-in[33] for Revit offered for free download. Combining these findings, Figure 13 presents the workflow developed for creating the CinderOSS BIM Library:

- Define required property dataset, and develop database structure aligned with IFC schema;
- Create generic BIM object in the authoring tool (Revit), and export it to BEXEL Manager. It is possible to do this step either through direct publication, or by exporting the IFC file from Revit;
- Augment the BIM objects dataset in the BEXEL Manager platform by adding required properties;
- Using platform's open API, develop a BEXEL Manager CINDERELA Add-In for synchronisation of datasets of BIM objects within the platform with the selected database file, related through a Product GUID (Globally Unique Identifier);
- Populate the database with actual values received from the material testing and LCA analysis conducted for innovative SRM-based products (materials), as well as for refurbished and reused components used in the CINDERELA demonstration cases;
- Synchronise the data by using CINDERELA Add-In;
- Export BIM objects augmented with dataset and values in the IFC file format;
- Export and synchronise BIM object properties with Revit by using Property Importer;
- Upload BIM object to CinderOSS platform in required IFC, and (optional) in the authoring tool format.

This workflow for data values synchronisation is also applicable when BIM objects are included in the building project (Figure 13). The workflow allows quick and simple data synchronisation for the CINDERELA demonstration projects, where the BIM model is developed and the dataset is defined, currently with no values, until material testing and LCA analyses are finalised.

[30] Honic et al., 2019 (same as 8)
[31] Pasini, D., Caffi, V., Daniotti, B., Spagnolo, S. L., & Pavan, A. (2017). The INNOVance BIM library approach. *Innovative Infrastructure Solutions*, *2*(1), 15.
[32] https://www.buildingsmart.org/compliance/software-certification/certified-software/
[33] https://bexelmanager.com/downloads/

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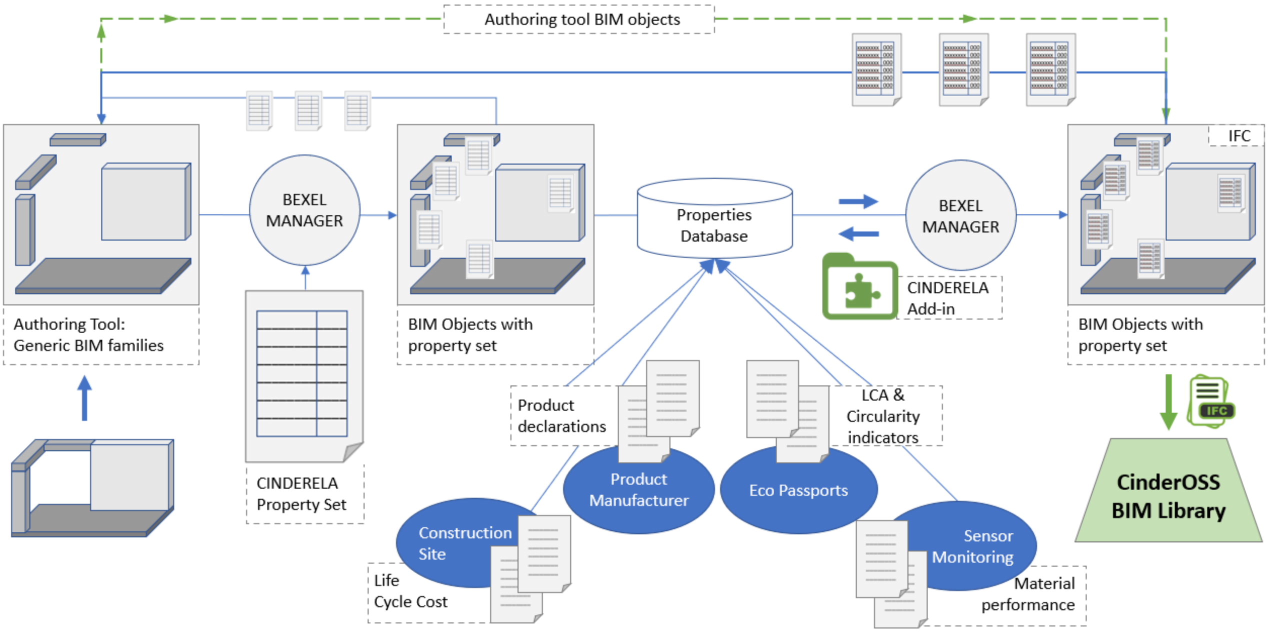

Figure 13 CINDERELA BIM Library development workflow

When populated with values, BIM objects are used to enhance BIM model development. Having such a product properties set allows the calculation of the total recycled or reused material on a building level in the early design stage of the project, when it is still possible to alter the design solutions in order to achieve a more sustainable design without large cost impacts. Further, the building end-of-life cycle scenario can be analysed since the information on the recyclability or reusability of the building components is available. Such calculations can be easily done using various BIM analysis platforms including the BEXEL Manager platform used in the above-presented CINDERELA workflow. Furthermore, this could be upgraded or transformed to various forms of building environmental impact analysis for the purpose of building certifications, which is the BIM use that is often a topic of scientific research.

4.5. Property dataset

As already discussed, the CinderOSS BIM Library property dataset has been developed to comply with CINDERELA's global goals. To ensure the widest possible dissemination of the BIM objects as well as to enable easy data integration and readability using most BIM software tools, the IFC file format was chosen. The following Table 1 presents the agreed dataset and its mapping to the IFC schema. Table 2 provides more details on the expected values of the properties.

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Table 1 CinderOSS BIM Library property data set

PROPERTY CATEGORY IfcPropertySet	PROPERTY NAME IfcProperty	PROPERTY UNIT IfcUnit	VALUE IfcValue	Mandatory property
GENERAL PRODUCT INFORMATION	Product name	[Text]	IfcName	*
	Material name	[Text]	IfcText	*
	Manufacturer	[Text]	IfcText	*
	Website (url)	[Text]	IfcText	
	Product code (GUID)	[Text]	IfcText	
	Category	[Text]	IfcEntity	*
LOCATION	Country abbreviation	[Text]	IfcText	*
	GPS coordinates	[Text]	IfcText	*
CIRCULAR INDICATORS	Waste type (text)	[Text]	IfcText	*
	Use of secondary materials [kg]	kg	IfcWeightMeasure	*
	Recycled/reused material (input) [%]	[Numeric]	IfcReal	*
	Recyclable (future scenario) [%]	[Numeric]	IfcReal	*
	Reusable (future scenario) [%]	[Numeric]	IfcReal	*
ENVIRONMENTAL INDICATORS (LCA)	Climate change [kg CO2 eq.]	kg	IfcWeightMeasure	*
	Water scarcity [m^3 water deprivation]	m3	IfcVolumeMeasure	*
	Resource use, minerals and metals [kg Sb eq.]	kg	IfcWeightMeasure	*
	Resource use, fossil fuels [MJ]	[Numeric]	IfcReal	*
LCC	LCC total cost [EUR]	[Numeric]	IfcReal	*
S-LCA	S-LCA overview	[Text]	IfcText	*
MATERIAL PROPERTIES	**For the concrete:**	-	-	
	Compressive strength [MPa]	[Numeric]	IfcReal	
	Tensile strength [MPa]	[Numeric]	IfcReal	
	Shear strength [MPa]	[Numeric]	IfcReal	
	Modulus of elasticity [GPa]	[Numeric]	IfcReal	
	For the geo-composites:	-	-	
	Humidity [%]	[Numeric]	IfcReal	
	Specific weight [kg/m^3]	[Numeric]	IfcReal	
	Required compactness	[Numeric]	IfcReal	
	Shear strength	[Numeric]	IfcReal	
SENSOR MONITORING	Sensor type	[Text]	IfcText	
	Sensor measurement unit	[Text]	IfcText	
	Sensor ID	[Text]	IfcText	
	Sensor value	[Numeric]	IfcReal	
	Sensor value timestamp	[DateTime]	IfcTimeMeasure	

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Table 2 Explanation of property data set

Property	Explanation
Product name	Custom textual property representing the object name e.g. Masonry_Block_RecyConrete, Structural_Wall_Green_Concrete_C30_R1-20
Material name	Custom textual property naming the SRM-based material used for the product e.g. RecyConrete, Green_Concrete_C30-R1-2 When a product is refurbished and reused this property takes the value *"Reused_component"*
Product code (GUID)	Key reference to information database, provided by the system
Country abbreviation	Country of production and implementation in ISO 3166-1 Alpha-3 Code format ex. SLO, SRB, NLD
Waste type	Textual property stating the code of waste according to European Waste Catalogue (EWC) or List of Waste (LoW), adopted on the provisions of the EU Waste Framework Directive.[34] If multiple waste types are being used for the same construction products, codes need to be separated by a semicolon. ex. 17 01 01; 17 01 02
Recycled/reused material (input) [%]	Proportion of material in the input to the production that has been recycled
Recyclable (future scenario) [%]	Proportion of the material in the product that will be recycled in a subsequent system
Reusable (future scenario) [%]	Proportion of the material in the product that will be reused in a subsequent system
Climate change [kg CO_2 eq]	Numeric value representing the climate change PEF impact category through kg CO_2 equivalent indicator
Water scarcity [m^3 water deprivation]	Numeric value representing resource depletion – water PEF impact category through m^3 of water used related to local scarcity of water indicator
Resource use, minerals and metals [kg Sb eq.]	Numeric value representing the resource depletion – mineral PEF impact category in kg antimony (Sb) equivalent indicator
Resource use, fossil fuels [MJ]	Numeric value representing the resource depletion – fossil PEF impact category in kg (Sb) equivalent
Use of secondary materials [kg]	Numeric value representing quantity of used secondary materials in the product in kg
LCC	Cost of an item throughout its life cycle, while fulfilling the performance requirements, calculated according to ISO15686-5:2017
S-LCA	Textual, descriptive parameter explaining the overall socio-economic performance of the product during its life cycle for all its stakeholders (workers, local community, society, consumers, value chain)
Material properties	Custom numeric properties related to important laboratory testing of the specific material, that confirm that material conforms with requirements such as structural strength and other physical characteristics
Sensor monitoring	Placeholder properties for future integration with sensor monitoring system

[34] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.C_.2018.124.01.0001.01.ENG;

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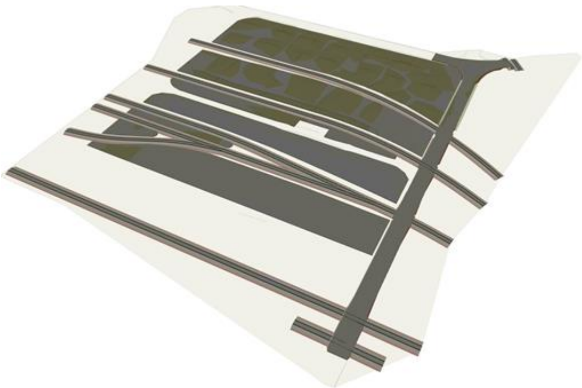
4.6. Demonstration cases BIM Families

In the early stages of the CINDERELA project, BIM models of three selected demonstration projects were developed with the implementation of generic families which now represent the building blocks of the CinderOSS BIM Library: (1) A small facility project in Maribor, Slovenia, shown in (Figure 14); (2) Revitalisation of a degraded area in Skopje, North Macedonia (Figure 15, left); (3) Road construction, Madrid, Spain (Figure 15, right).

Figure 14 CINDERELA demonstration project in Dogose, Maribor, Slovenia



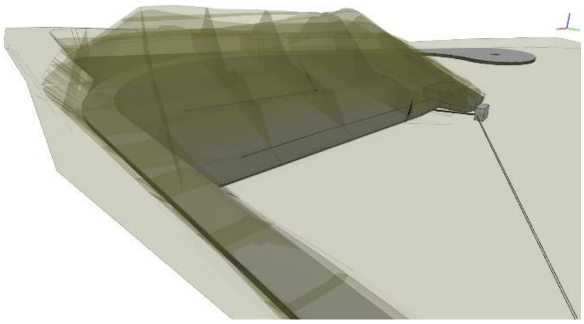


Figure 15 CINDERELA demonstration projects in North Macedonia (left), Spain (right)

The initial 3D BIM models were established using the Revit and Civil 3D software platforms and further enriched with CINDERELA properties set through the BEXEL Manager. With the BEXEL Manager Properties importer, all properties were synchronised back in Revit, providing an efficient way to manipulate and add defined properties to all elements of the BIM model.

Extracting BIM Families from the BIM models and developing them in accordance with the BIM

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Execution Plan allowed the creation of a sorted repository of reusable BIM objects in the form of the BIM Library. Each BIM family includes predefined attribute fields for required information which are continuously being loaded with appropriate data.

The manipulation of CINDERELA properties in the later phases of the project is significantly simplified by automatic changes of predefined attributes (adding or changing property values) in the CinderOSS BIM Library, by entering property values within the database that will automatically update all the BIM families within the CinderOSS BIM Library through a developed add-in procedure.

In addition to this benefit, prior to uploading a BIM object to the CinderOSS BIM platform, an automatic check will be performed to analyse and ensure that all BIM objects in the CinderOSS BIM Library are populated with all the required property values.

Figures 16 to 19 show several examples of BIM families with predefined properties as per Table 1.

- Example 1 – Green concrete block
- Example 2 – Reused window
- Example 3 – Green concrete slab
- Example 4 – Reused roofing

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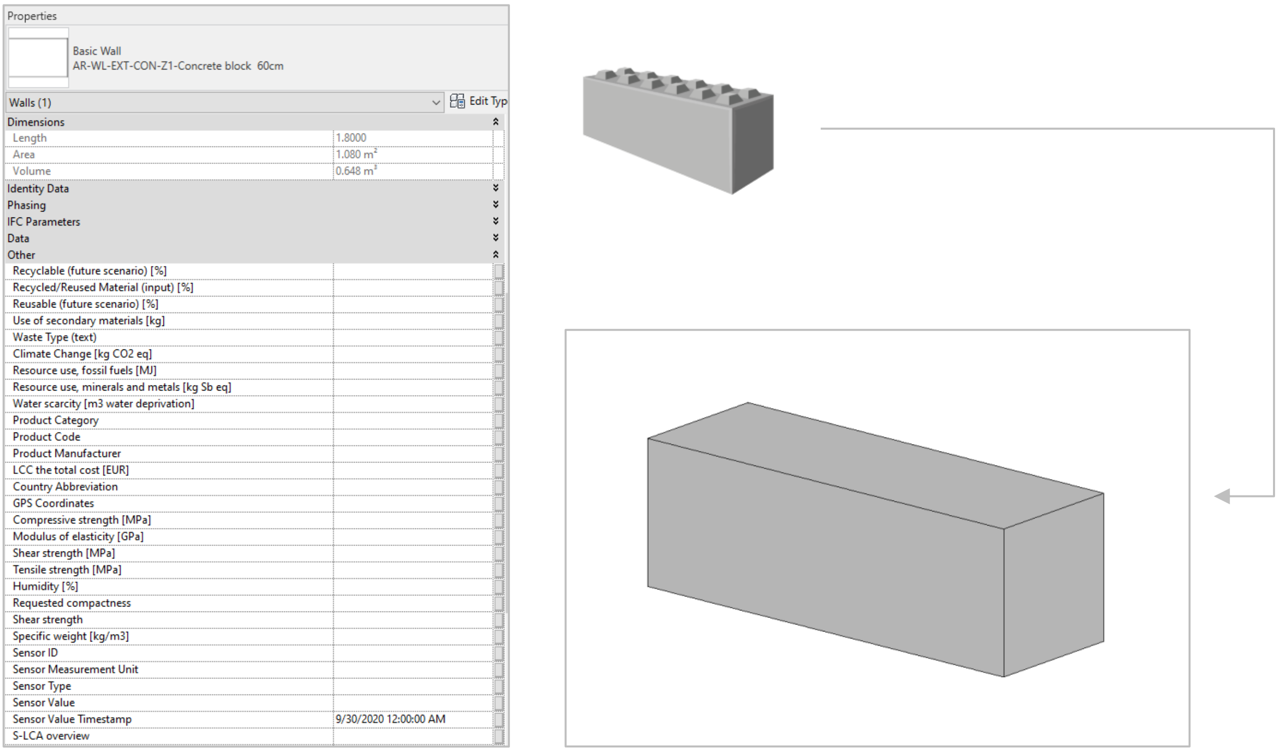

Figure 16 CinderOSS BIM Library – BIM object example – Green concrete block

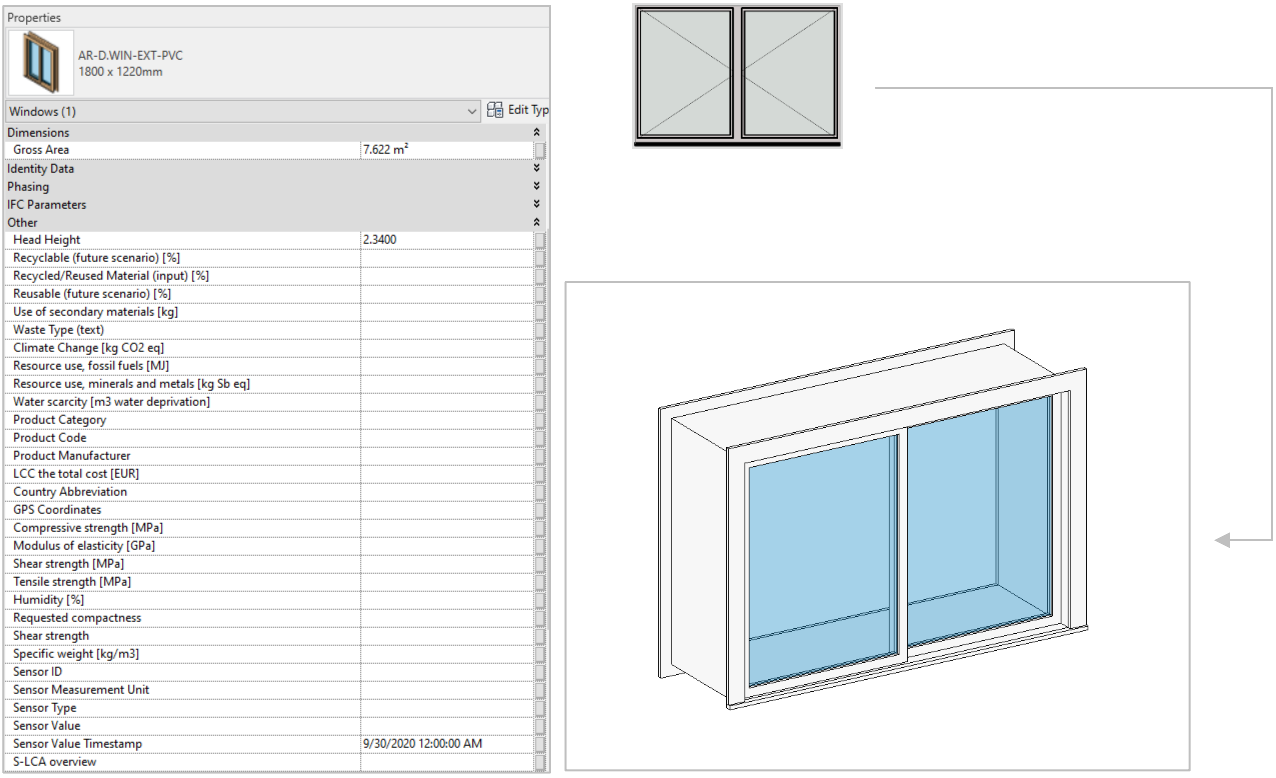

Figure 17 CinderOSS BIM Library – BIM object example – Reused window

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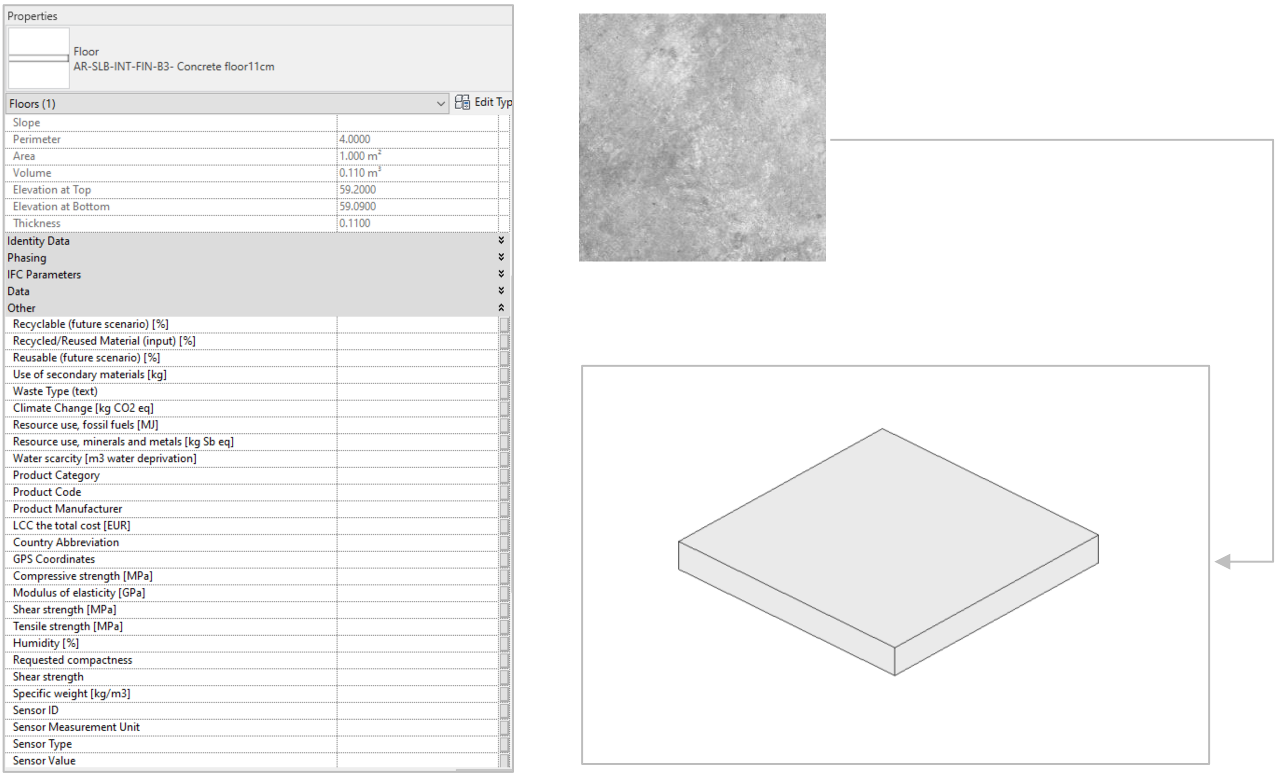

Figure 18 CinderOSS BIM Library – BIM object example – Green concrete slab

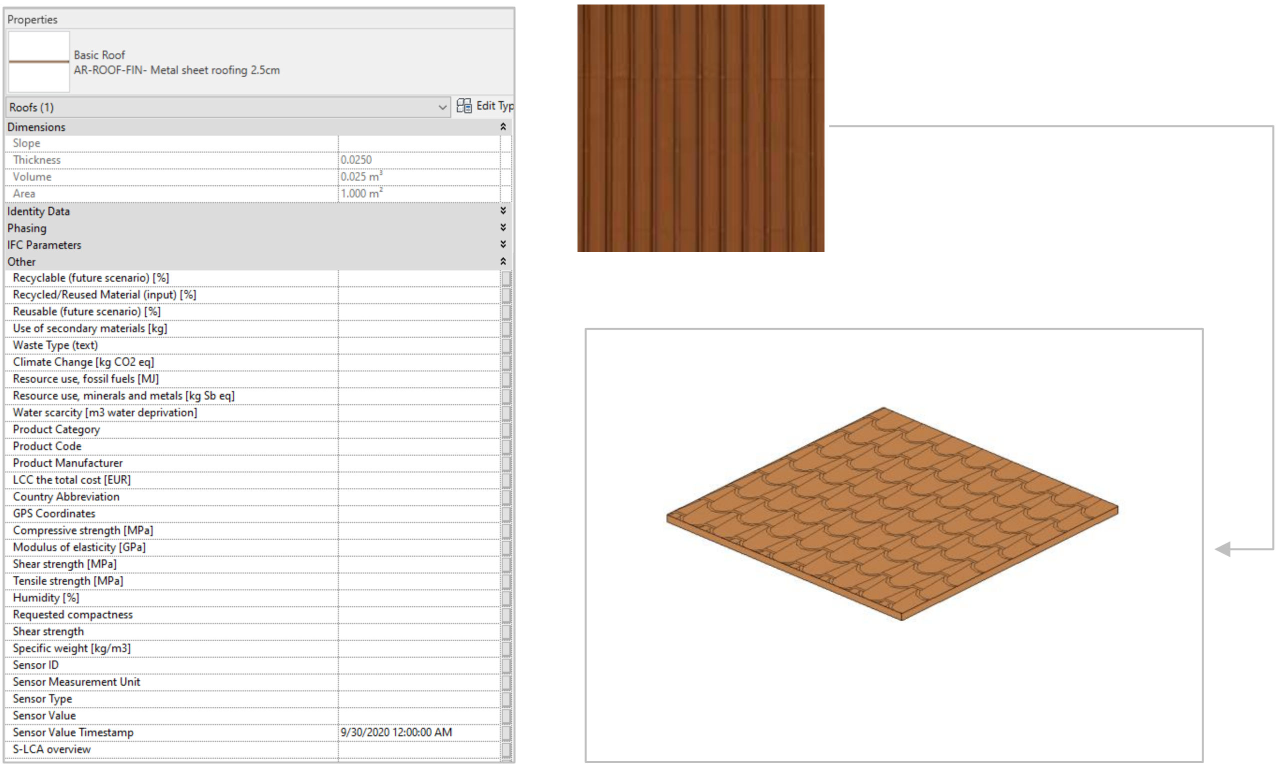

Figure 19 CinderOSS BIM Library – BIM object example – Reused roofing

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5. CinderOSS BIM Library platform

To ensure the self-sustainability of the CinderOSS platform upon the completion of the CINDERELA project, end-user interactions are being analysed in two time spots – during the CINDERELA project and after its completion. This is reflected to the BIM Library module as well, mainly in terms of stakeholders' involvement, the data provision process and system maintenance.

The BIM object as the value unit is discussed in section 4, whereas the targeted user groups' (participants') expectations, their in-platform interactions, platform interface, functionalities and technology are explained in the following sections.

5.1. Target user groups

CinderOSS is intended to provide a wide knowledge database on circular business models in AEC and therefore to attract different industry stakeholders, starting from those involved in waste management, manufacturers, architects and engineers, and construction companies, up to owners and policy makers. More details on the entire CinderOSS digital business ecosystem have been explained in deliverable D4.1 and will be further detailed in D4.2, while this deliverable will focus only on the BIM Library module.

The BIM Library module complements the information provided within the Production & Construction part of the CinderOSS. The CINDERELA BIM Library is not intended to provide a large repository of BIM objects that will accelerate the BIM model development process, but to define the information structure, focused on the waste management, sustainability aspects and circular economy goals in order to support BIM design and construction processes, improve the dissemination of the SRM-based construction products, and enable stakeholders to compare construction products based on the above-mentioned metadata.

Derived from these goals and the CinderOSS BIM Library module structure, the user groups that can benefit the most are defined, and the target groups presented in Table 3 include manufacturers, who can promote their products and the circularity character of their production, and waste holders or waste brokers, who are able to identify the waste-to-resource opportunities. Architects and engineers can search for and compare products, as well as directly utilise the BIM objects and related metadata for development and analysis of their BIM models. Having standardised product data libraries can result in higher productivity and improvement of the real-estate development process. Therefore, also the owners are recognised as a user group who are able to identify products in line with their project vision.

Table 3 CinderOSS BIM Library target groups

BIM Library Aspect	Target group	Value
Platform	Manufacturers	Promotion of SRM-based products
	Waste holders	Identifying waste-to-resource opportunities
BIM Objects	Architects & engineers	Use directly for model development
BIM Objects information database	Owners	Identify SRM-based products aligned to their project vision
	Architects & engineers	Compare sustainable and physical characteristics of SRM-based construction products

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5.1.1 Interactions during CINDERELA project

The process of developing the CinderOSS BIM Library module integrates multiple WP and the expertise of consortium members. BIM objects created during the design development process of the demonstration cases, based on the design inputs from WP5, are augmented with sustainability and product-specific data layers to represent the initial BIM library.

For the purpose of analysing stakeholders' interactions, the following entities were recognised and related to the project's WP activities:

- Product manufacturer (WP3, WP7);
- Designers (WP5);
- Platform users – Demonstration Projects Execution (WP6, WP7);
- Platform owner (WP4);

Also, the BIM objects will be interconnected with the product sustainability properties database through a Product Code as presented in section 4.4, so Add-in for the automatic updating of BIM objects will be developed based on BEXEL Manager. The interaction scheme is presented in Figure 20.

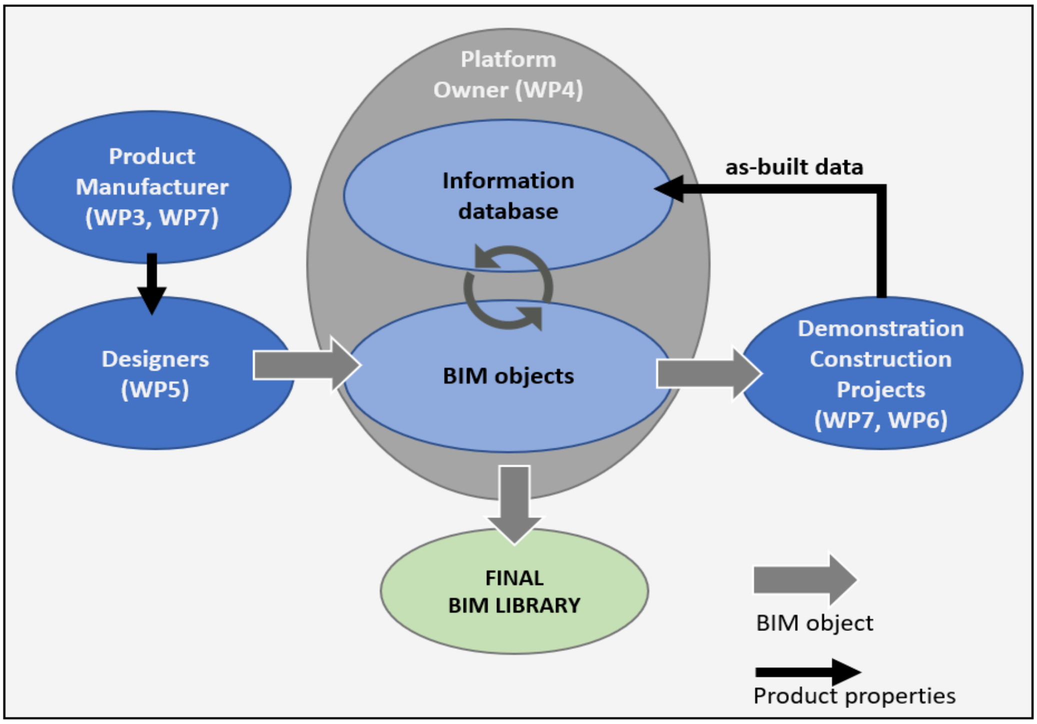

Figure 20 CinderOSS BIM Library interactions during project

5.1.2 Interactions upon CINDERELA completion

The CinderOSS BIM Library module is being developed to allow uploading of the BIM objects by product manufacturers (or third-party BIM objects developers) directly to the library upon which it is officially launched.

Users are then able to analyse the products' sustainability datasheet directly from the platform. which will facilitate further interactions between the stakeholders and the use of the SRM-based construction products in design and construction.

The interaction scheme within the CinderOSS BIM Library module is presented in Figure 21.

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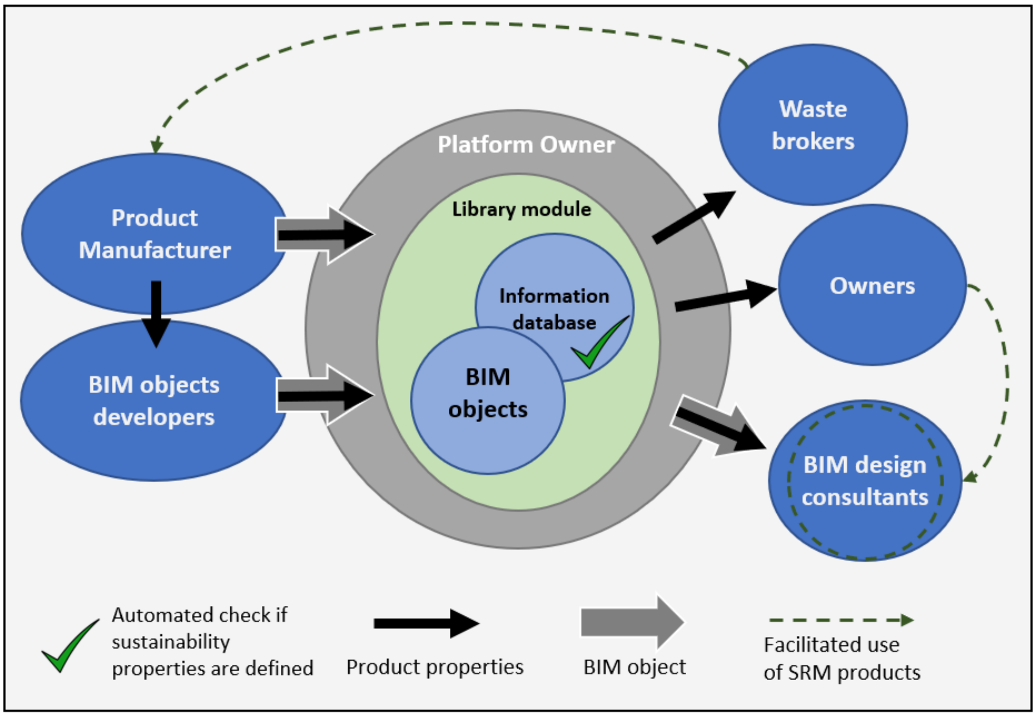

Figure 21 CinderOSS BIM Library – operational phase

Considering that the focus of the CinderOSS BIM Library is to arrange and promote information on SRM-based construction products and their sustainability indicators in the vendor-neutral file format, two conditions are defined for the BIM object to be uploaded:

- openBIM IFC file format is mandatory;
- sustainability properties are defined.

BIM objects can be uploaded in the IFC file format in versions 2x3 or newer (ISO 16739:2018). Such format could be imported and analysed within hundreds of BIM software tools. buildingSMART International has established a procedure for software certification and the list of IFC certified solutions can be found on the buildingSMART webpage.[35] With the IFC file provided, other software-related file formats used (RVT or RFA for Revit) can be added as well.

Having the IFC file also enables the second condition to be checked through the automated procedure executed by the CinderOSS platform during the file uploading process. The procedure browses through the IFC file, and searches for mandatory metadata, according to Table 1.

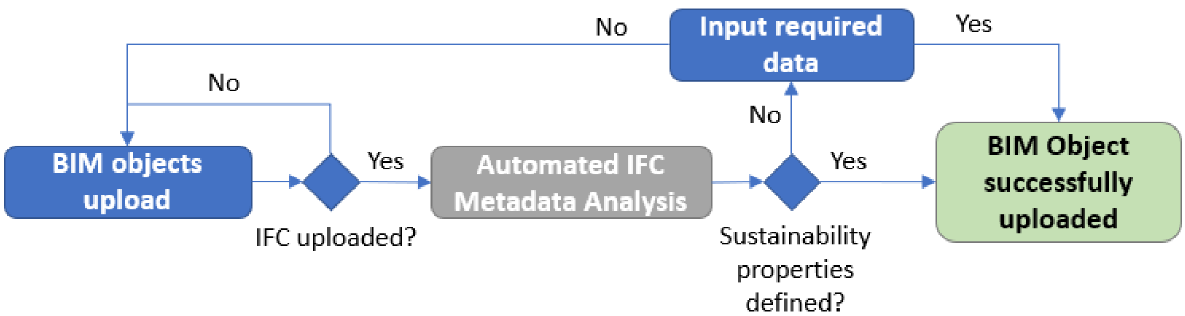

Figure 22 CinderOSS BIM Library upload process

[35] https://www.buildingsmart.org/compliance/software-certification/certified-software/

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If some data is missing, the issue is directly reported to the user, who can choose either to input the required data through the online input interface or to upload the corrected IFC file. In that way the system ensures automatically, without engaging the platform owner, that every object within the CinderOSS BIM Library has the sustainability parameters defined as mandatory. The uploading process is presented in Figure 22.

Additionally to the BIM objects, manufacturers can upload the image representing the BIM object, and the corresponding specification document or brochure in PDF file format.

5.2. Interface

In order for the CinderOSS platform to successfully serve its function and promote SRM-based products and sustainability indicators, it is necessary to make the data easily accessible, searchable and comparable. It is common for existing platforms to lack these functions when it comes to sustainability parameters,[36] which is the issue that the CinderOSS platform addresses.

After the successful uploading of the BIM object to the CinderOSS BIM Library module, the system automatically extracts the mandatory data fields from the BIM object, tags the object within the platform, and includes it in the object page.

The system then allows the user to filter available BIM objects according to the values of the BIM object properties (textual), such as Product name, Category, Manufacturer, Waste type, etc.; or to sort them by the environmental indicators or life cycle cost values (numeric). Additionally, the comparison of two elements side by side is allowed.

Based on the available data, the system will offer users further links to similar BIM objects, other related resources of the CinderOSS, or links to the Digital Business Ecosystem when applicable. These functions of the CinderOSS will be defined in the following project stages.

[36] Bahrami et al., 2019 (same as 17)

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6. CONCLUSION

Advanced information management is proving to be a game-changer in AEC, with BIM taking a serious role throughout the entire project life cycle. Starting from early design development, throughout construction planning and monitoring to facility management and finally disassembly planning, BIM is being widely used. With this intention, the CINDERELA project offers an approach to capture and disseminate a fit-for-purpose standardised set of information on the product environmental footprint and the circularity footprint of the products or building components by means of the BIM Library. The proposed dataset includes standard impact categories that are usually discussed within the LCA and circularity analysis, which is why they can be marked as mandatory properties, ensuring data consistency without jeopardising the future growth of the library repository. The workflow of library development and the mechanism for ensuring data conformity are developed by utilising advanced BIM data-handling procedures supported by the open application programming interface (API) of the BIM analyses tool.

By exposing the BIM Library to the broad community within the CinderOSS Production & Construction section, the engagement of multiple types of stakeholders is expected, with a wide range of activities such as information-sharing, and uploading or downloading of particular BIM objects from the library repository.

The platform target groups include product manufacturers as the usual contributors to similar systems, waste brokers, architects and engineers, and finally owners (investors). It is expected that manufacturers will tend to promote their sustainable products on the platform, waste brokers to find the sales channels and waste-to-product opportunities, and designers to use it for market research, information gathering or BIM object download in the process of BIM model development for their specific projects, etc.

This will result in mutual relations between the stakeholders within the CinderOSS BIM Library module, which will, along with the simple use of the BIM objects offered (and subsequently the products) in the design development process, result in greater dissemination of the SRM-based products and their innovation, therefore contributing to the main CINDERELA objectives.

This deliverable has developed the basis for further analysis of the CinderOSS BIM module within project WP4, as well as data collection in WP6 and WP7, and should complete the envisioned process and result in a fully functional BIM Library module at the CinderOSS launch.