

Parametric design methodology for developing BIM object libraries in construction site modeling

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ABSTRACT

The adoption of Building Information Modeling (BIM) in construction site layout planning and activity scheduling faces challenges due to the lack of standardized approaches for digitally reproducing and organizing site elements that meet information requirements of diverse regulatory frameworks and stakeholders' use cases. This paper addresses the question of how to streamline the development of BIM objects for construction site modeling by proposing a vendor-neutral parametric design methodology and introduces a dedicated hierarchical structure for BIM object libraries to support users in their implementation. The methodology includes a six-step process for creating informative content, parametric geometries, and documentation, and is demonstrated through the development and implementation of a construction site BIM object library suitable for the Italian context. This approach fills a gap in BIM object development standards and offers a foundation for future research, benefiting practitioners and industry stakeholders involved in BIM-based site layout modeling and activity planning.

1. Introduction

Nowadays, with the adoption of Building Information Modeling (BIM), the management of information throughout the whole project life cycle has been increasingly digitalized and enhanced [1]. In everyday practice, designers rely heavily on BIM object libraries to effectively develop building models regardless of the chosen authoring environment and design discipline. These objects, meant as digital counterparts of real building components and entities, comprise all the physical features (e.g., 3D geometry, materials), as well as the technical information (e.g., mechanical properties, thermal performance, installation methods, cost, other specifications) required for the appointed model, use cases, and integrated workflows. Nonetheless, while for commercial purposes, many libraries of BIM objects have been made available by software vendors and building product manufacturers and are periodically updated, most of them are limited to building representation (e.g., architectural, structural, systems components). Regarding the construction phase, BIM-based design and management processes (e.g., site layout planning, activities scheduling and monitoring, health and safety management) still lack dedicated libraries. The few available consist mostly of non-parametric 3D models with scarce additional information

and require significant customization and rework to be enriched with data and parametric capabilities to be suitable for integrated BIM workflows. The benefits of BIM-based construction planning and management have been widely acknowledged since its early adoption. Leveraging construction site models, advanced visualization, and simulation tools can support predicting issues, preventing accidents, and assessing the risks to which workers are exposed in these typically highly hazardous working environments [2–4]. Early identification of conflicts among parallel activities and solution of spatial clashes avoids errors, delays, and resource waste and improves site productivity [5–7]. However, implementing such approaches in this field still struggles to gain momentum. The lack of standardized approaches for the development of construction site BIM objects and libraries suitable for effective construction site layout and activities modeling stands among the principal causes.

To address this issue, the present paper proposes an original approach for developing and organizing BIM object libraries for modeling construction site layouts and activities. The Italian standard UNI 11337–1 defines the BIM objects library as a digital environment for gathering and sharing graphic and alphanumeric model objects. BIM objects are virtualizations of geometric and non-geometric attributes

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related to physical or spatial entities associated with a set of works and their processes [8]. This must be distinguished from some features offered by vendor-specific software applications, such as Autodesk Revit™. For instance, Autodesk Revit offers the Family feature, a group of combined objects that create a single, reusable component. Families can be created in Revit and saved for later use in other projects, making adding standard elements to a design more straightforward and faster [9]. However, BIM object libraries must be vendor-neutral and widely shared.

This paper presents the structure of a BIM objects library, tailored to be used in real-world site modeling scenarios and designed to simplify practitioners' adoption. Then, a methodology for developing parametric BIM objects for construction site elements is discussed and validated. Following the discussion of relevant related works (Section 2) and the identification of the research objectives (Section 3), the library structure development methodology is presented in Section 4 and demonstrated in Section 6. The BIM object development methodology is explained in detail in Section 7 and evaluated with the results of a case study implementation for one of the considered objects (i.e., site lift, Section 7). Eventually, the conclusions and the outlook on future developments are provided in Section 8.

2. Background

The introduction of BIM in the Architecture, Engineering, and Construction (AEC) industry brought the possibility to disrupt long-established processes through the *"digital representation of the physical and functional characteristics of a facility"* into information models, hence *"forming a reliable basis for decisions during its life cycle"* [10]. In turn, using three-dimensional models of buildings comprising their parametrized components improves access, production, and sharing of information of interest among the actors involved in the project [11]. In this regard, it is acknowledged that a mature BIM adoption is crucial for project success and relies on open standards to enhance interoperability and collaboration among different stakeholders and disciplines. Concerning the construction phase, BIM-based workflows benefit planning and scheduling processes [12] at every project scale, from building to infrastructure [13,14], and contribute to improving productivity and cost management [15]. In the last decade, several studies have demonstrated that BIM models can generate dynamic construction site layouts and extract data for spatial and activity optimization [16]. BIM-based automated safety rule checking can be applied to streamline hazard recognition and evaluation, and risk assessment activities [2,3,17]. Furthermore, the enhanced spatial understanding capabilities and information visualization provided by construction site BIM models have been exploited for transferring both general and project-specific health and safety knowledge with the implementation of Virtual Reality (VR) technologies for the reproduction of site scenarios for workers' safety training and activity planning [18–23]. This section provides an overview of the state-of-the-art BIM-based construction site planning and scheduling, focusing on site layout, activities modeling, and standing research gaps. This paper addresses these implementation barriers with the proposed workflow for developing construction site BIM objects and libraries.

2.1. BIM as a parametric design tool

BIM is highly acknowledged for its potential for enhancing capabilities throughout a building's whole lifecycle [24]. BIM parametric structure and its integrated data exchange and knowledge mining capability [25] have been widely used to enhance design information transfer [26] and features optimization [27], production quality management [28], construction teams' coordination [29], construction quality control [30], construction documentation [31], and information extraction from on-site inspection reports [32]. Combining the parametric characteristic of BIM with the capabilities of Application

Programming Interface (API), unnecessary design repetitions can be avoided [33]. This can reduce the inherent inflexibility in the building design stage while meeting the need for high coordination necessary for the OSC design stage [34]. For instance, Liu et al. [35] adopted a parametric BIM design approach to planning roof sheathing installation for prefabricated buildings to minimize material waste and reduce carbon footprint. Song et al. [36] advocated the potential of augmented reality (AR) literature for digital fabrication and assembly of construction projects.

Moreover, the parametric modeling capability observed in BIM can be used to trigger an innovative workflow in planning modular and prefabricated construction. If the technical monitoring frameworks necessary for such workflows are implemented, construction waste can be minimized [37]. For example, Ramaji and Menari [38] presented a specific product architecture information model for modular multi-story buildings. To increase design and production efficiency, they employed the Level of Details (LoDs) available in BIM to address construction issues encountered in the design phase and align LoDs and different levels of their product architecture model.

Other studies focused on optimizing design process efficiency through implementing BIM parametric design tools in developing designs based on a Design for Manufacturing and Assembly (DfMA) method, where all the requirements in 'design,' 'production,' and 'assembly' of PBs are achieved to prevent repetitive work in these three stages. For example, Yuan et al. [39] proposed an innovative framework for DfMA implementation using BIM parametric modeling for domestic housing. Once modeling was completed, the production information model of the house was optimized. Such a framework can use the BIM family templates and API to create the needed elements and assembly functions not existing in BIM as BIM-redevelopment. The newly created elements are added to the BIM standard parametric prefabricated component library. Following a lean construction and DfMA methodology, Gbadamosi et al. [6] proposed an effective method for optimizing the assembly process of prefabricated elements. In their study, Revit software, along with a Dynamo algorithmic environment, was implemented to benefit from the parametric modeling capability of BIM and to transfer design information using the Industry Foundation Classes (IFC) format.

Similarly, Li et al. [40] emphasized the need for an integrated conceptual framework to understand present studies and signpost future research based on BIM capabilities. Moreover, it can simplify the decision-making process by construction industry stakeholders. In their proposed framework, the parametric capabilities of BIM and data exchange through information format constitute a crucial role. This framework was used to develop a design for the X(DFX) strategy.

2.2. BIM objects development and product information exchange

With the diffusion of BIM, the representation of building components' geometry and informative content through their digital counterparts assumed a crucial role in building design, information management, and effective project delivery. BIM objects are more than "building blocks" of a building model; they allow for storing, organizing, and providing substantial technical information with their geometrical and non-geometrical parameters [41,42]. Depending on the design discipline, heterogeneous informative requirements determine the adoption of specifically developed BIM object libraries. Wang et al. [43] investigated the implementation of automatic or semi-automatic approaches for BIM object development based on the identification of critical parameters for their characterization to enable the adoption of computational methods to generate different libraries.

Furthermore, despite ongoing standardization efforts, BIM libraries must be tailored to accommodate regional and national differences in building techniques, industry characteristics, maturity levels, and regulatory frameworks, even within the same disciplines. In the Italian context, the creation of InnovANCE database [44] for building process

information standardization aimed to provide procedures and criteria for developing BIM objects and libraries to support BIM-based collaborative processes [45]. These efforts, in turn, led to the development of a BIM library available as an online platform for interoperable construction product data sharing (BIMReL) based on the direct involvement of manufacturers and industry operators in the creation of digital counterparts of their products and aiming to save the users the effort and errors in the retrieval of technical and commercial information to be included in the production of the related BIM object [46]. Likewise, Lu et al. investigated the development of open-access BIM libraries to facilitate building design and information management in Hong Kong [47]. Recently Getuli [48] proposed the development of integrated ontologies in a knowledge-base in order to map the information of site workspaces management to support the development of AI-based reasoning mechanisms. Besides, numerous manufacturers already provide and maintain libraries of BIM objects developed according to their criteria for use by designers in their practice, making it difficult to compare similar products and define their compliance with specific regulations and requirements. To address this issue and support quality assessment in prefabricated construction, Sun and Kim developed an automated checking system for modular BIM objects [49].

Despite the cited contributions and similar efforts to improve the classification of BIM objects and libraries and hence the interoperability and the construction products information exchange [50], an acknowledged standardized approach to be applied to different contexts and disciplines is still missing.

2.3. BIM-based workflows for construction site planning

Limiting the scope to the design and execution of the construction phase, the benefits provided by BIM-based site planning and construction activities scheduling are demonstrated in numerous studies related to different use cases and purposes. In particular, the introduction of the temporal information to the BIM objects, commonly referred to as 4D BIM modeling, improves visualization and understanding capabilities of the spatiotemporal evolution of construction site layouts, allowing early issues detection and solution of clashing parallel activities, eventually improving site productivity and workers' health and safety. For these reasons, construction 4D modeling is nowadays a foundational step for many advanced BIM-based applications [51]: workspace planning, simulation, and management [5,52,53]; construction site health and safety code checking [54]; construction site logistics management [55]; machinery and workers onsite operation simulation [56] and construction planning [57]. In addition, for 4D BIM-based modeling methodologies, site planning and scheduling information of construction activities together with their required resources are fundamental and that information are usually linked with corresponding information objects in the BIM model of the project's design [58,59]. This approach, which is based on the assumption to have site information objects, has allowed the development of various applications for construction planning and management demonstrating the importance value to provide designers with BIM-based objects libraries. Hammad et al. [60] consider the location and target components of activities on the construction site to define the location of temporary facilities. Andayesh and Sadehpour [61] similarly develop a 4D model to assign space to objects on site at the date and for the duration they are required. Other research studies have used 4D modeling to target onsite logistics. Said and El-Rayes [62] integrate project contractor and suppliers' data to optimize material supply and minimize logistics costs, and Bortolini et al. [63] support site logistics planning for the installation of prefabricated building systems. More recent studies have aimed to fully integrate site layout planning and activities scheduling by using Site Information Models and the data generated and included in such models even to ensure efficient and safe construction processes. Recently Sorbi et al. [64] proposed a framework to simulate site activities and site risks that combining 4D Site Information Models and based on Agent-based simulation, Getuli

et al. developed a BIM-based code checking methodology for construction safety optimization and a construction site progress monitoring methodology by using site information objects and BIM models [54,65] and also to enhance workers safety training [66].

However, despite the efforts to automate and optimize 4D BIM model development [5,67,68], an acknowledged standardized approach that supports designers in generating construction site layouts and activity plans is still lacking. Collinge et al. proposed a classification of safety risks to support BIM-based health and safety planning and management workflows [69]. In contrast, others leverage semantic web technologies to reason on construction site BIM models [70,71]. Nonetheless, the prevalent use of BIM objects (e.g., machines, equipment, scaffoldings) as tridimensional placeholders, mainly constituted of geometric models with very few informative contents and scarce or absent parametric behavior, significantly affects the value of construction site models and hinders the effective integration of BIM in construction management workflows.

2.4. Research gap

Nowadays, the established adoption of the BIM methodology in the AEC sector makes available diverse authoring environments with a set of default BIM libraries for the three main disciplines – architecture, MEP, structure – and tools for further creation, exchange, and management of customized parametric objects. Moreover, building components manufacturers increasingly promote their products, allowing for the sharing of their digital counterparts both in open and proprietary formats of the leading BIM authoring software vendors. Contributions and approaches for the development of BIM objects and libraries have been proposed in research for specific disciplines and applications – railway infrastructures [14], structural elements [72], construction workers' VR safety training [21] -while regulatory authorities and industry consortia in various countries have provided and periodically updated guidelines either general or dedicated to a specific context, such as Singapore [73]; USA [74,75]; Hong Kong [76].

However, as discussed above, a lack of BIM object libraries is dedicated to modeling and simulating construction site layouts and activities. The few site's object BIM libraries are mainly collections of 3D objects without parametric specifications and with little information attached. This fact leads to considerable inconvenience regarding construction site design and management. Most objects are missing basic information, making it difficult to exploit them in an integrated BIM-based design workflow. Moreover, the differences and peculiarities of the various BIM authoring environments adopted in the industry make it challenging to develop a standardized protocol that can harmonize disparate BIM object development models, often oriented or more suitable for other disciplines (e.g., architecture, MEP). Additionally, contractual concerns over the sharing of detailed property data in BIM models further complicate the development of integrated solutions, as stakeholders may be reluctant to provide sensitive information.

The present paper aims to address these research gaps by proposing a six-step method for developing parametric BIM objects to effectively model construction site layouts and activities and the hierarchical structure of a library dedicated to their organization and storage.

3. Research objectives

This paper aims to foster BIM-based construction site modeling and simulation processes by defining a methodology for developing libraries of parametric objects of construction site resources other than building elements (e.g., site facilities, machines, equipment). As stated above, the main concern of this study consisted in overcoming the lack of relevant manufacturers' data in digital site objects, overlooked from acknowledged modeling approaches, despite their crucial role for several domain-specific applications (e.g., spatial planning, cost estimation, risk assessment, environmental impact evaluation). For this purpose, the

present paper pursues the following objectives:

- Support practitioners in BIM-based construction site layout modeling, activities planning, and progress monitoring processes, i. e., 4D and 5D BIM, with an effective classification of construction site objects and entities tailored to support diverse workflows that shall comply with the deliverables requirements of national regulations and local industry contexts.
- Foster the development of parametric construction site BIM objects that represent actual marketed products, comprising physical and technical characteristics corresponding to manufacturers' data.

To achieve these objectives, the research (Fig. 1) involved the initial review of the literature concerning current international BIM standards and guidelines, best practices, and case studies related to construction site modeling carried out together with the analysis of the Italian context and regulations to identify specific information requirements for design deliverables (e.g., site layout, health and safety plans). From this background, a BIM object development workflow specific for construction site modeling has been drawn focusing on two distinct areas: “BIM library” structure and “BIM object” development. The former regards the hierarchical organization of construction site entities oriented to implementing BIM-based construction management and health and safety management workflows and results in an original structure compliant with the Italian national regulatory context. The latter regards the definition, implementation, and evaluation of the proposed workflow for developing parametric BIM objects of construction site entities and products available on the market. The choice of a parametric approach, integrating heterogeneous manufacturers' data directly as objects' parameters, aims to facilitate the collaboration and exchange of disciplinary information among the actors involved in construction sites' operations within BIM environments. The developed workflow is vendor-neutral; hence, it supports but purposely does not reach the actual object digital implementation to be carried out on a BIM authoring environment. Eventually, the proposed approach is evaluated with a prototypical implementation of the library structure and the development of 36 object typologies, as discussed in Sections 4–7.

4. Construction site object library structure - development methodology

Independently by the design discipline, BIM library structures directly impact the users' capabilities of object retrieval, comparison, and selection and thus should be informed by the peculiar requirements of the related tasks. Modeling construction site layouts and activities for the numerous phases of a project requires the consideration of highly heterogeneous elements – from fences and signage to excavators and cranes – serving different purposes and complying to seldom overlapping regulatory frameworks. In this paragraph, we propose a methodology for developing construction site BIM object libraries with a three-levels structure that supports the users in their implementation, namely *sections*, *categories*, and *typologies* (see Fig. 2).

This choice was informed by the review of the literature on BIM-based construction site layout planning and activity scheduling, BIM standards and guidelines, as well as regulations related to management and workforce health and safety on construction sites, with particular reference to the Italian context. The methodology is demonstrated through the development of a construction site BIM object library (Section 6). As outlined below, three key requirements were considered to guide the development of the library structure at each level: the principal domain or functional area of the site object, the related regulatory framework, and the general design workflows they serve.

At the top level, *sections* are identified following three criteria:

- **Functional domain separation:** Each section should represent a distinct functional domain within construction site planning, avoiding overlaps. The separation can be guided by the primary purpose or role of the items within that section (e.g., construction site organization).
- **Regulatory compliance:** Sections should align with regulatory frameworks and safety standards relevant to construction site planning and management, helping to adhere to local, national, and international regulations. Each section should group objects that are governed by similar regulatory requirements (e.g., emergency management).
- **User-centric accessibility:** The library should be intuitive and easy to navigate from the first level for its diverse users, who might include site planners, safety officers, and project managers. Each section

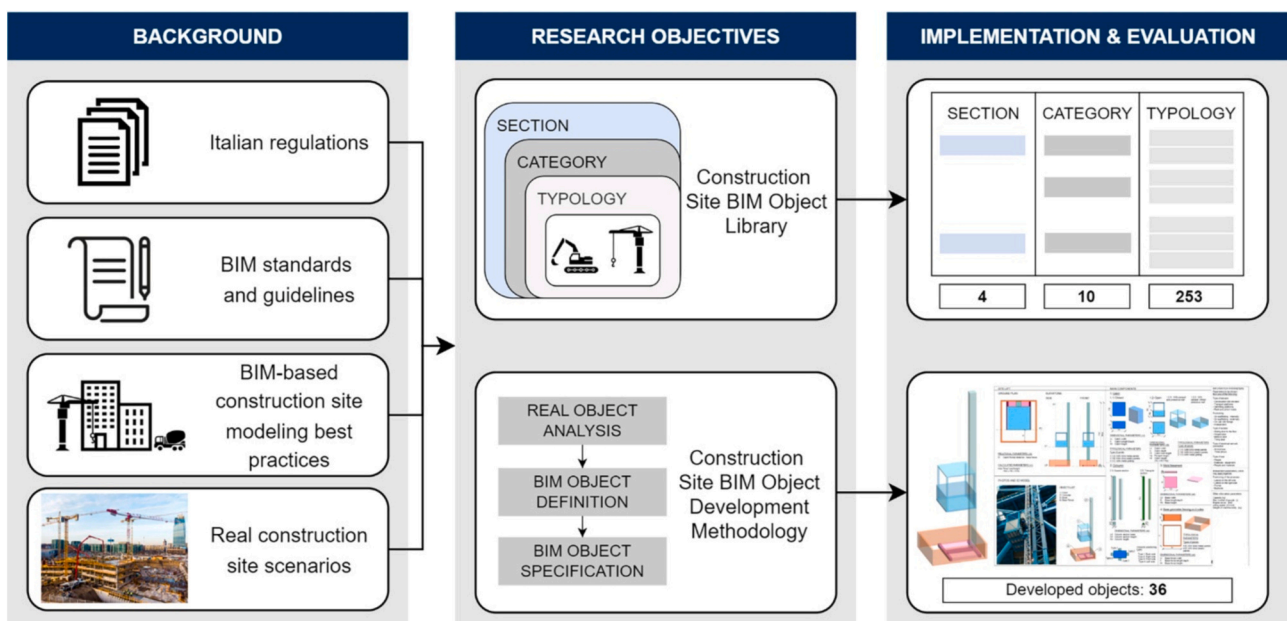


Fig. 1. Research workflow.



Fig. 2. Construction site BIM object library organization criteria.

should be logically grouped based on how users typically think about and approach site planning tasks (e.g., machines).

For each section, site objects are distinguished in different *categories* based on the following three criteria:

- *Specific functional grouping*: Each category within a section serves to group entities on specific functions or roles they play within the correspondent domain. This ensures that each category is unambiguously defined and focuses on a distinct and clear subset of objects, facilitating easier identification and access.
- *Regulatory compliance*: Categories should reflect regulatory requirements that apply to different types of objects. This ensures that users can easily find items that are compliant with the same regulations and respond to comparable design principles.
- *User workflow and practicality*: The identification of the categories should follow the typical workflow and practical needs of the users. The library navigation should be intuitive and support efficient retrieval of objects based on user tasks.

Eventually, at the lowest level, site objects are grouped by *typology*

according to the following two criteria:

- *Detailed functional specification*: Typologies should represent detailed functional specifications within their category, ensuring precise classification and easy identification of items based on their specific functions or characteristics.
- *Product-specific attributes*: Each typology should be defined based on product-specific attributes which may include dimensions, capacity, material, technology, or compliance with certain standards. This ensures that each typology within a category addresses specific technical requirements and quality standards, facilitating informed decision-making for users.

5. Construction site object library structure – Case study implementation

To evaluate the capabilities of the proposed construction site BIM object library hierarchical organization and development methodology, a case study that considered the Italian national regulatory context and practitioners' needs has been implemented. Health and safety regulations in force for construction sites and the mandatory requirements of

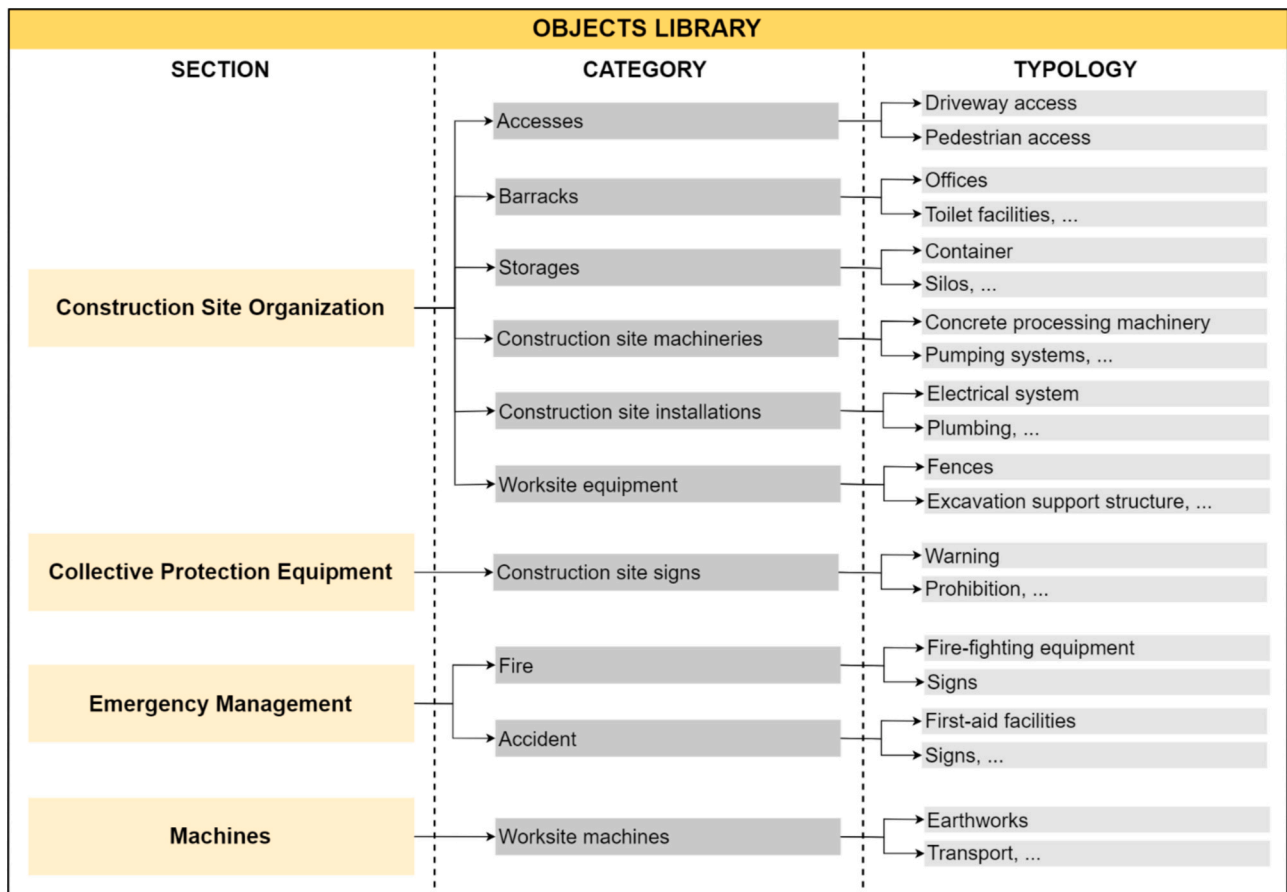


Fig. 3. Structure of the site object library (extract).

the deliverables concerning site layout planning and activity scheduling led to the implementation of a prototype of the construction site BIM object library, which resulted in four sections, ten categories, and 253 typologies, as reported in Appendix A. With reference to the library extract provided in Fig. 3 the four identified sections are defined as follow:

- *Construction site organization* – Objects employed to define the spatial and functional configuration of the construction site through its different phases and layouts, also allowing for identifying work zones and related risks. These include, for example, barracks, delimitations, equipment, and systems serving site plants and facilities.
- *Collective protection equipment* – Objects installed to protect all workers against the risks identified in the various work zones and during the planned activities. Among these are diverse categories, from collective fall protection systems (e.g., safety nets) to construction site signs (e.g., warning signs).
- *Emergency management* – Objects provided for managing emergencies on the construction site, such as fire and accidents. These include, i.e. fire extinguishers and first aid kits available in specific predefined site locations and all the specific warning and prescription signs.
- *Machines* – This section covers the heterogeneous set of machines that are employed on-site for specific construction activities, such as material transportation (truck, forklift), lifting (crane), processing (concrete mixer, iron bender), and handling (concrete pump); earthworks (excavator, bulldozer). In the planning phase, besides technical specifications for productivity purposes, all the spatial and safety requirements shall be considered to prevent clashes among parallel activities and guarantee the workers' safety.

Within the discussed sections, ten categories have been defined, including their object typologies according to the discussed criteria. Each considered construction site entity is eventually represented as a specific instance of its related parametric typology.

6. Construction site BIM object - development methodology

Complimentarily to the library structure discussed above, this paragraph presents a workflow for developing parametric objects dedicated to BIM-based modeling, planning, and management of construction sites (Fig. 4). The process comprises six steps organized into three progressive phases. It starts with analyzing the target real object as it is commercially available and employed on-site, continues with the definition of its parametric features and the aggregation criteria of its components, and eventually results in the detailed specification of its digital counterpart. As described in the case study implementation reported in Section 7, the final output consists of reports and technical sheets designed to inform BIM specialists and drive the development of the appointed BIM object regardless of the adopted authoring environment.

6.1. Market analysis

The initial phase of the BIM object development regards the analysis of the correspondent actual entity as marketed and employed on construction sites. Therefore, the first step of the analysis focuses on its related market segment and identifies the significant manufacturers within the expected scope of adoption of the object and library (Fig. 5). In this regard, the national context can be assumed as the ideal dimension for the scope due to the variability of the regulations in force in different countries and the local differences in construction practices. Among the main selection criteria for a suitable set of manufacturers, vendor-neutrality and the prompt accessibility to the technical product documentation necessary for the analysis plays a crucial role in the company's market share and reputation. Further additional criteria (e.g., special features, sustainability) could be considered to address

specific object/library uses. However, the number of manufacturers selected should be balanced to have enough product variability without incurring unnecessary rework.

In this paper, the set of considered manufacturers has been limited to a maximum of five for each analyzed object. Then, for each of them, the analysis of the marketed models is carried out to retrieve information for recurrent characteristics to be reported in dedicated tables (see Table 2). Among these, both physical properties and intangible object features are included and organized in the following sections:

- *Types* – For the analyzed object, i.e., product, manufacturers commonly offer models and types with different features and capabilities. Therefore, in the first section of the table, the relevant types are listed per column with a correspondent identification code and a brief typological description. These types serve as references for the sequent information.
- *Components* – The main object components are identified and listed per row, and their distinctive characteristics are reported for the different object types.
- *Geometry* – The main dimensional characteristics of the objects, such as the bounding box and components' maximum extension range, are identified and listed for each type. These dimensions often distinguish different marketed products and indicate relevant parameters to be considered in the BIM object development.
- *Functions* – The functional characteristics of the analyzed object are listed and specified for the different identified types.
- *Spatial requirements* – This section reports crucial manufacturers' data that inform designers on the correct employment of the analyzed object on site. Installation requirements, maintenance spaces, and relative distances to other site objects are relevant for static objects, while operational spaces and safety distances shall be considered for dynamic objects (e.g., machines).
- *Materials* – Information related to the materials adopted for the object or its components are listed in this section, where relevant.
- *Other features* – This last section reports all the additional requirements and features relevant to the object specification and employment on-site and have not been previously considered.

6.2. Product breakdown structure (PBS) definition

Following real object data collection, the second step addresses the definition of the object Product Breakdown Structure (PBS) according to a hierarchical decomposition of a minimum of three levels, as shown in Fig. 6 and according to the criteria reported in Table 1 (see Fig. 11 for case study implementation). This defines the relevance of the different object's parts and informs the following development stages about the level of detail (e.g., geometrical, graphical) and the level of information (e.g., non-geometrical) that shall be implemented for its digital representation. Eventually, only the geometrical and non-geometrical information related to the main components, including the related sub-components, shall be characterized in the following stage. Instead, all the components assumed as secondary in this phase shall not be explicitly developed within the final BIM object and should be referred to only for complementary considerations.

6.3. Characterization of the components

Once the object PBS is, the information that will develop the BIM object's 3D geometry and typological distinction (Fig. 7) is identified, extracted, and formalized from the collected data for each component and sub-component, distinguishing between *dimensional* and *typological* characteristics.

The former defines a fixed and editable dimension that will drive the object geometry parametric behavior. The latter comprises a piece of additional information that distinguishes different object types. Considering the example site lift analyzed in Section 7, the cabin's

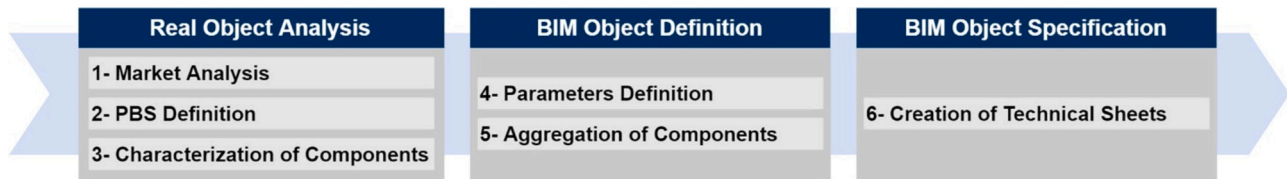


Fig. 4. Construction site BIM Objects development methodology.

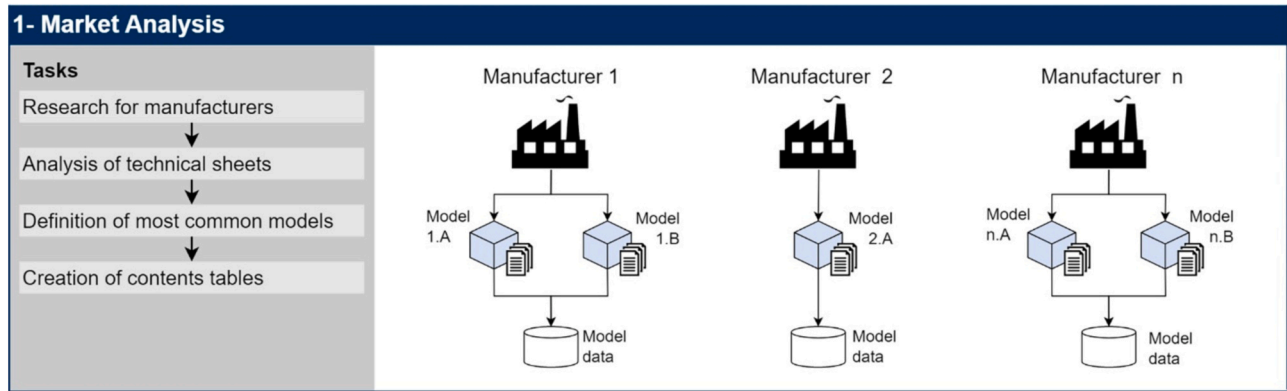


Fig. 5. Step 1 – Analysis of the market of the construction site entity.

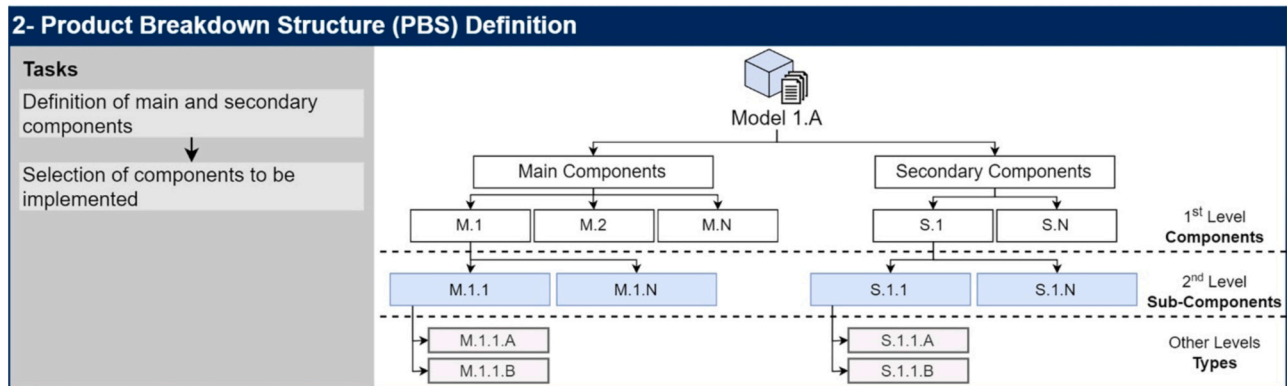


Fig. 6. Step 2 – Product Breakdown Structure (PBS) definition of the construction site entity.

length, width, and height represent dimensional characteristics, while whether the cabin is enclosed or without a roof determines a typological characteristic.

6.4. Definition of parameters

Entering the BIM object definition phase with all the information obtained from the real object analysis, the definition of its parametric behavior and informative content is addressed in the present step (Fig. 8). For each main component and related sub-components, the characteristics previously identified are further processed, discarded, or aggregated to be implemented as a parameter in the BIM object. In turn, depending on its function, the parameter's type is chosen among the following:

- **Geometrical** – For the 3D geometry of the object, its global positioning and relative configuration among its various components can have fixed, enumerated, editable, or calculated values. In particular, calculated values are for properties that shall not be editable by the user because predetermined rules, formulas, or relations, among other non-calculated parameters, limit them.

- **Relational** – For the relative configuration of different object components, resulting from spatial requirements and consisting of dimensional or alignment constraints.
- **Typological** – For the distinction of different object types depending on a predetermined set of values for a certain feature. Depending on the selection option, parameters that accept only a single value from an enumerated set, i.e., toggle, and parameters that allow for the simultaneous selection of multiple values, i.e., checkbox, can be considered.
- **Information** – For technical data and complimentary specifications necessary to comprehensively evaluate and plan the object employment in the construction site (e.g., productivity, cost).

Eventually, all the determined parameters are expressed via *name*, *type*, and *unit of measurement* (where relevant) and are reported in a comprehensive table (see Tables 7–9). Moreover, to support the implementation of the different BIM object's parts for each component, a dedicated sheet is compiled with the following information (see Fig. 12):

Table 1
Product Breakdown Structure (PBS) classification levels.

Level	Description	Example – Construction site lift
1) Functional relevance (Main/Secondary components)	Components are distinguished for their functional relevance: main components are those without which the object cannot fulfill its core function; secondary components complement the core function.	Main components: Cabin; column. Secondary components: emergency brake; onboard control panel.
2) Components	A component is an element or an aggregate of distinct elements (sub-components) with well-recognizable physical, typological, and geometrical characteristics.	Column, as the aggregation of several metal trusses with a fundamental load-bearing function.
3) Sub-components	A sub-component corresponds to a single identifiable element with certain physical, typological, and geometrical characteristics with no function but only within a component.	Panels forming the cabin. Metal trusses form the column.
Further levels	Further decomposition levels shall be considered for complex objects if different types or variants of the superior sub-component can be distinguished.	Metal trusses are composed of elements with different sections, materials, or mechanical characteristics.

- **Description** – Brief explanation aiming to provide information about the component relationship with the whole object, dimensions, uses, and different variants and types that are commercially available.
- **Types diagram** – Representation of the component's typological variants.
- **3D Geometry**: 3D Geometric representation of the component in all its listed typological variants with the specification of parametric dimensions.
- **Typological properties**: All properties that distinguish different component typologies and their possible values.

6.5. Aggregation of components

After identifying the relevant parameters and information for each object component, this step defines spatial and functional aggregation criteria (Fig. 9). The former consists of identifying the various components' individual and mutual geometric relations in terms of *reference planes* and *levels*, *rotation axis*, and *constraints* (e.g., parallel, perpendicular, coincident). It enables the correct implementation of the BIM object. The latter regards functional constraints defined through parametric relations. Among these shall be considered further dimensional constraints (e.g., for a machine: operator's safety distance or relative position) and general requirements (e.g., energy supply, installation of other specific components). Once the identification of the components' aggregation criteria is concluded, a 3D representation of the components assembled accordingly and representing the BIM object geometrical prototype is modelled and annotated with the appointed parameters (see Fig. 13).

3- Characterization of Components

Tasks

Analysis of Sub-Component for each Components

Definition of the characteristics of Sub-Components

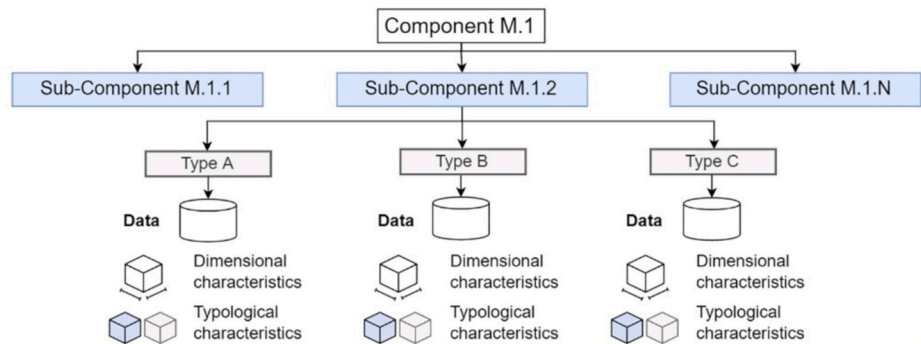


Fig. 7. Step 3 – Characterization of the components of the construction site entity.

4- Parameters Definition

Tasks

Selection of characteristics to be implemented as parameters

Definition of different types of parameters

Creation of scheme for each Sub-Components

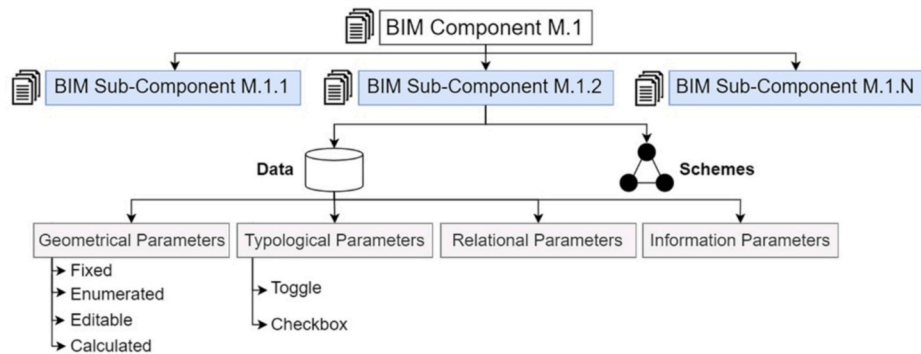


Fig. 8. Step 4 – Definition of the parameters for each component.

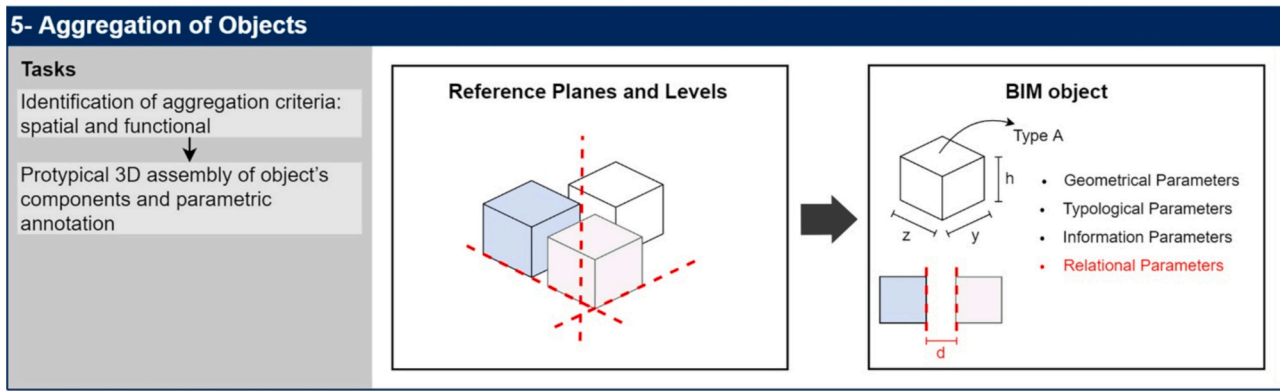


Fig. 9. Step 5 – Aggregation of components.

6.6. Creation of technical sheets

The final step of the proposed construction site BIM object development workflow consists of conveying the information previously produced into a synthetic technical sheet intended to support developers during the object's implementation (Fig. 10).

The layout of the technical sheet has been structured to facilitate the understanding of the parametric characteristics and behavior of the object and rely on graphical representations to provide most of the relevant information. In turn, this includes the following four sections:

- *Plan and elevation view* – 2D plan and elevation view of the complete object with the specification of its parameters, such as total height, length, width, reference planes, levels, etc.
- *Pictures and axonometric view* – Representation of the real object through photos and 3D view of the complete object's volumes, including all the identified main components.
- *Components*: Representation of each object's component with the related types and parameters.
- *List of parameters*: All data and information related to the object are organized according to the categories discussed above (see Section **Error! Reference source not found.**).

In Section 7, the results of implementing the proposed workflow for one of the construction site objects analyzed in this paper, i.e., site lift, are reported and discussed.

7. Construction site BIM object - case study implementation

To evaluate the capabilities of the proposed construction site BIM object library and development workflow, the methodology has been implemented in a case study that considered the Italian national regulatory context and practitioners' needs. As discussed in Section 4, the analysis of the health and safety regulations in force for construction sites and the mandatory requirements of the deliverables concerning site layout planning and activity scheduling led to the implementation of a prototype of the construction site BIM object library, which resulted in 4 sections, ten categories, and 253 typologies. Then, for 36 of these objects' typologies, the presented BIM object development workflow has been implemented and evaluated. This section reports the analysis and development of a construction site lift with the results of each intermediate step.

7.1. Site lift – market analysis

Site lifts and construction hoists are machines used for the vertical transport of both personnel and materials on a construction site. This type of equipment usually consists of a cabin moved by an electric motor. In developing a BIM object for a construction site lift to be

adopted in the Italian national context, the first step related to the market analysis considered an initial set of nine manufacturers. Five were removed due to their minor market share and scarce accessibility to technical product documentation. The marketed models were analyzed for the remaining four manufacturers, and the related relevant information was reported in dedicated tables. Table 2 shows an extract for the products of the manufacturer Nidec TEA.¹

7.2. Site lift – product breakdown structure

Based on the collected manufacturers' data, the second step of the analysis concerned the definition of the related PBS. Eight components were distinguished at the second level (see Fig. 11). Four main components were identified and further characterized in the following steps under geometrical and informative perspectives: *cabin*, *column*, *base*, and *fence*. The cabin and column components also required the introduction of additional sub-components, such as *access* and *anchors*. Besides, four components were listed as secondary; hence, they were not further characterized: *lower anti-crushing grid*, *engine*, *emergency brake*, and *on-board control panel*.

7.3. Site lift – characterization of the components

Once the site lift components and sub-components have been identified, their significant features are defined and organized into homogeneous dimensional and typological characteristics that will drive the implementation of the corresponding BIM object data and geometry. Table 3 summarizes the identified site lift characteristics together with additional product specifications.

7.4. Site lift – parameters definition

In this step, each component's identified dimensional and typological characteristics were converted into correspondent parameters. Two types of geometrical parameters were implemented for the dimensional characteristics, namely, *editable* and *calculated* (see Table 4). The second type identifies some of the dimensional characteristics of the object, such as the total height, which are not directly editable by the user but result from formulas dependent on other parameters.

Then, the typological characteristics identified in the market analysis phase are examined, and the corresponding typological parameters, including value enumerations, are defined. For the considered site lift, both *toggle* and *checkbox* parameters were defined (see Table 5).

Other site lift relevant characteristics, which do not affect the parametric behavior of the related BIM object but shall be attached to it, implemented as *information parameters*, and listed below (see Table 6).

¹ <https://www.tea-online.it/>

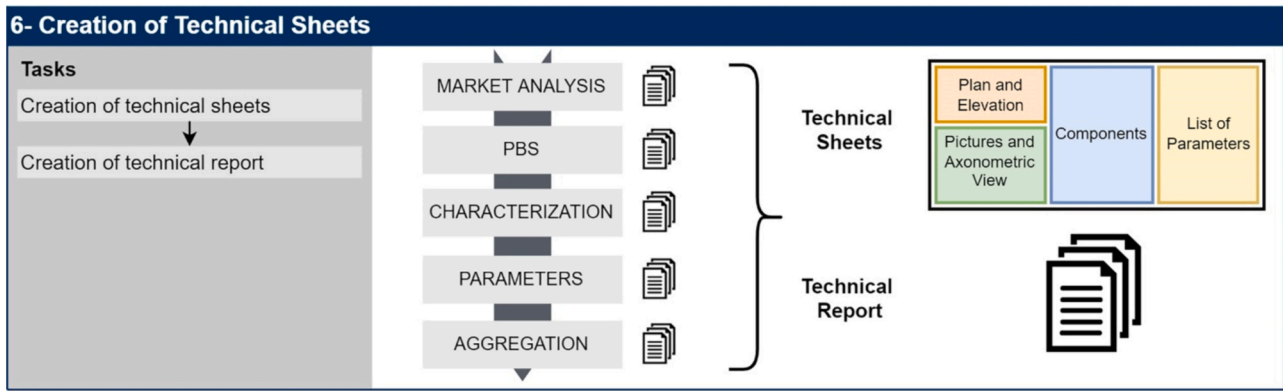


Fig. 10. Step 6 – Creation of technical sheets.

Table 2

Site lift – market analysis result (extract for Nidec TEA).

Manufacturer	Nidec TEA					
Types	Model Type	PTE500P	PTE1000P	PME700P	LIFT2000S	PTE1500P
	Type of lift	Rack and pinion hoists	Rack and pinion hoists	Rack and pinion hoists	Construction site lift	Construction site lift
	Anchors	Intermediate anchor support	Intermediate anchor support	Intermediate anchor support	Intermediate anchor support	Intermediate anchor support
Components	Cabin	Open cabin with parapet	Open cabin with parapet	Open cabin with parapet	Closed cabin	Open cabin with parapet and roof
	Column	Metal grid with triangular section	Metal grid with triangular section	Metal grid with triangular section	Metal grid with square section	Metal grid with square section
	Base	Metallic frame base	Metallic frame base	Metallic frame base	Metallic frame base	Metallic frame base
Geometry	Power supply	Three-phase	Three-phase	Three-phase	Three-phase	Three-phase
	Cabin length [mm]	1600	1750	1500	3550	3400
	Cabin width [mm]	1200	1400	970	1600	1400
	Cabin height [mm]	1100	1100	1100	2800	1100
	Base length [mm]	1800	2230	1894	–	2280
	Base width [mm]	1400	1750	1700	–	2180
	Column section length [mm]	253	400	400	450	450
	Column section height [mm]	289	355	355	450	450
	Maximum column height [m]	120	150	120	200	150
	Use	Transport of materials and people	Transport of materials and people	Transport of materials and people	Transport of materials and people	Transport of materials and people
Spatial requirements	Object positioning	Wall fastening	Wall fastening	Wall fastening	Wall fastening	Wall fastening
Materials	Type of material	–	–	–	–	–
	Lifting speed [m/min]	12	12 (People) 24 (Materials)	12	40	12 (People) 24 (Materials)
	Load capacity [kg]	500	1000	700	2000	1500
Other features	Engine power output [kW]	2,5	8	2,5	11	8
	Electric power [A]	6,3	20	18	58	41
	Weight [kg]	823	1100	650	1475	1660

Once the general parameters of the BIM object have been defined, a technical sheet summarizing all the geometrical and typological information was produced for each main component. Fig. 12 reports the technical sheet for the analyzed cabin component. Similar technical sheets have been produced for the other three main components: column, base, and fence.

7.5. Site lift – aggregation criteria

In the last step of the “BIM object definition” phase, the relational parameters that determine the aggregation criteria of the different site lift components were defined together with the necessary reference planes and levels. In this case, two elevation levels and one vertical plane were identified (see Fig. 13).

- L_0 : Reference level – Ground $\pm 0,00$ m;

- L_1 : Reference level – Cabin; for the elevation at which the cabin bottom plane is modelled;
- P_1 : Cabin Front Plane – serve as a reference for additional spatial requirements (e.g., the distance D to be maintained between the fence and the cabin entrance).

7.6. Site lift – technical sheet

Finally, all the geometrical and typological specifications for the analyzed site lift were conveyed in the dedicated technical sheet (see Fig. 14), which is meant to serve as a synthetic guideline for correctly implementing the BIM object within the proposed site object library.

8. Conclusions

To effectively realize the construction sector’s digital transition, it is

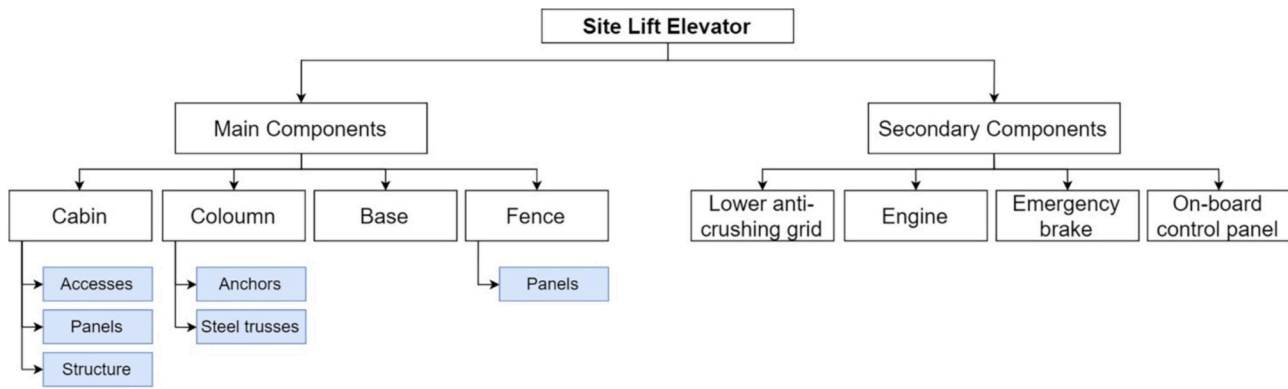


Fig. 11. Site lift – Product breakdown structure (PBS).

Table 3

Site lift – Dimensional and Typological characteristics.

Dimensional Characteristics		
Dimensions	Height	
	Length	
	Width	
	Bounding box	
Spatial requirements	Positioning	On scaffolding (internally or externally) On the wall with anchoring
		Freestanding
		Single-sided
	Positioning of accesses	Lateral on both sides Frontal Frontal and lateral on both sides.
Typological Characteristics		
Type of lift	Construction site lift	
	Transport platforms	
	Self-raising platforms	
	Rack and pinion hoists	
Type of use	Transport of persons	
	Transport of materials and equipment	
	Transport of people and materials	
	Enclosed cabin	
Type of cabin	Open cabin with parapets and protective roof	
	Open cabin with parapets	
Type of column	Metal truss with square section	
	Metal truss with triangular section	
Type of base	Metal frame	
	Sliding floor door	
	Hinged door	
Type of accesses	Folding door	
	Tilt door	
Type of power connection	Single-phase	
	Three-phase	
Additional Specifications		
System features	Load capacity [kg]	
	Max. number of transportable persons	
	Motor power [kW]	
	Lifting speed [m/min]	
	Total weight (empty) [kg]	

Table 4

Site lift – Geometrical parameters.

Category	Reference	Name	Type	Unit of Measure
Editable	L_c	Cabin length	Length	[m]
	l_c	Cabin width	Length	[m]
	H_t	Cabin roof height	Length	[m]
	H_p	Cabin parapet height	Length	[m]
	L_{cl}	Column length	Length	[m]
	LCL	Column width	Length	[m]
	H_{cl}	Column height	Length	[m]
	L_b	Base length	Length	[m]
	l_b	Base width	Length	[m]
	H_b	Base height	Length	[m]
Calculated	L_r	Fence length	Length	[m]
	H_r	Fence height	Length	[m]
	LR	Fence width	Length	[m]
	$H_t = H_{cl} + H_b$	Total hoist height	Length	[m]
	$H_c = H_t + H_p$	Cabin height	Length	[m]

Table 5

Site lift – Typological parameters.

Parameter name	Value selection type	Enumerated values
Type of lift	Toggle	- Construction site lift - Transport platforms - Self-raising platforms - Rack and pinion hoists
Type of column	Toggle	- Metal grid with square section - Metal grid with triangular section
Type of base	Toggle	- Metal frame – H-shaped - Metal frame – V-shaped
Type of cabin	Toggle	- Enclosed box cabin - Cabin with parapet and protective roof - Cabin with parapet without a protective roof
Type of accesses	Toggle	- Sliding floor door - Hinged door - Folding door - Tilt door
Type of power connection	Toggle	- Single-phase - Three-phase
Type of use	Toggle	- Transport of persons - Transport of materials and equipment - Transport of people and materials
Positioning	Toggle	- On scaffolding (internally) - On scaffolding (externally) - On the wall with anchoring - Freestanding
Positioning of accesses	Checkbox	- Lateral, single-sided - Lateral, both sides - Frontal - Frontal and lateral on both sides

crucial to harness the benefits brought by BIM methodologies and technologies throughout the whole project lifecycle. However, BIM is still critically under-adopted during construction and for site health and safety management purposes. Many previous studies emphasized the importance of stakeholders' involvement in the design stage [77]. The effectiveness of BIM has been proven in reducing rework and the economic and environmental costs caused by the waste of materials [37], and it has been widely advocated as a parametric design tool to meet the stakeholders' expectations and DfMA principles [78]. In this regard, there is an increasing body of research emphasizing the unique technical data exchange capabilities of BIM along with immersive technologies such as augmented reality (AR) and virtual reality (VR) through open

Table 6
Site lift – Information parameters.

Parameter name	Parameter type	Unit of Measure
Load Capacity	Weight	[kg]
Max. number of transportable persons	Number	–
Motor power	Power	[kW]
Lifting speed	Velocity	[m/min]
Machine weight	Weight	[kg]

BIM standards and IFC information format [79]. Numerous studies reveal that these capabilities can create innovative solutions for the collaboration among individuals and different parties engaged in construction supply chains [80] and production planning and control [28]. However, a notable dearth of studies sought to provide a design framework for construction sites, a framework in which due attention is paid concurrently to customer requirements and construction efficiency and minimized environmental impacts. On a commendable effort, Cao et al. [81] presented a parametric solution based on providing different building configurations with various pre-designed components and building assemblies, which are designed according to the DfMA requirements. Yet despite this research, attention predominantly focuses on customer requirements at the configuration level, ignoring the basis for customizing the building and its components throughout the design process.

The proposed parametric design methodology and approach in this study for the organization of the related libraries and supporting implementations, along with the practical integrated approaches for implementation in the construction sites, can be used as a foundation to determine the stakeholders' collaboration with the design teams. Consequently, this paper enhances the stages before data exchange between the stakeholders and design section and advances previous studies conducted in this area. Compared to the collaboration process defined in BIM standards such as CDE available in ISO 19650-1:2018 standard [82], the proposed collaboration framework aims explicitly to facilitate the exchange of disciplinary information among the actors involved in construction sites' operations within BIM environments. However, this study acknowledges the current lack of scalability in applying the developed approach to other types of BIM objects. While the paper primarily focuses on BIM object development for populating site models with construction planning and scheduling information, future efforts could extend this methodology to support the modeling of entities needed during the operational phase, such as IoT devices and sensors. These technologies are increasingly vital for managing smart, sustainable buildings. Given their role in realizing and maintaining Digital Twins, along with the heterogeneity and constant evolution of features and capabilities in marketed products, our approach could be adapted and tested for this diverse and dynamic field, addressing the current lack of standardized approaches or libraries. This could

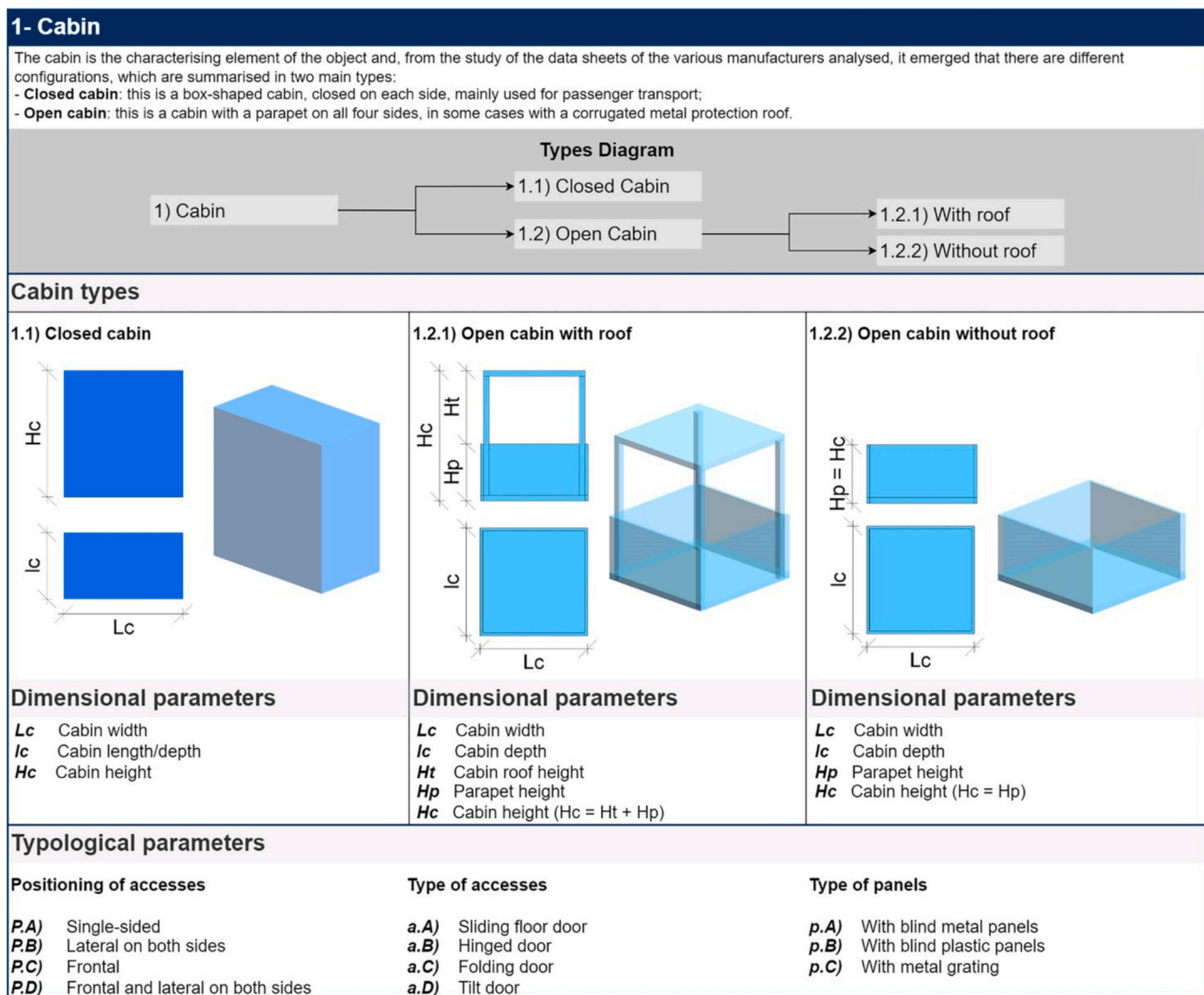


Fig. 12. Site lift cabin component – Technical sheet.

Aggregation of Components

Components

- 1) Cabin
- 2) Column
- 3) Base
- 4) Fence

Reference planes and levels

- L_0 Ground Ref. Level
 L_1 Cabin Ref. Level
 P_1 Cabin Frontal Plane

Relational parameters

- D Distance cabin-fence [m]

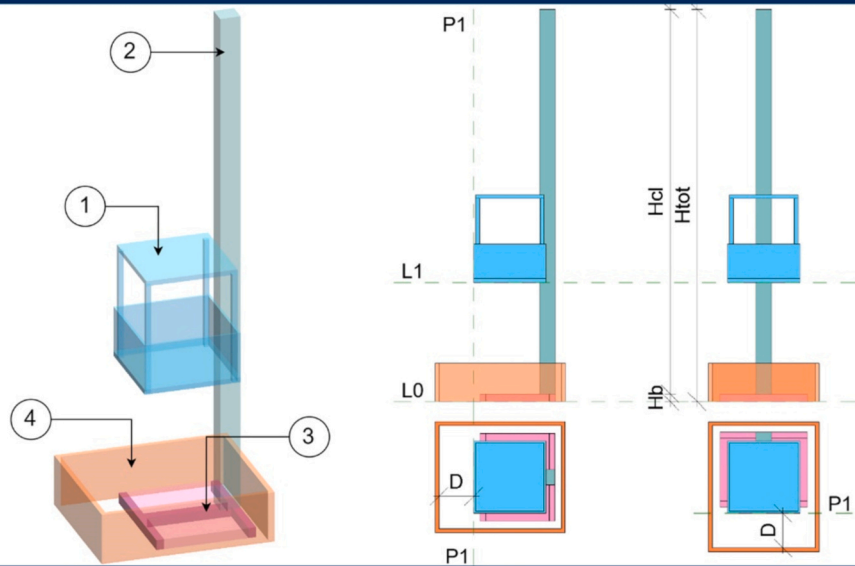


Fig. 13. Site lift components' aggregation – Reference levels and planes.

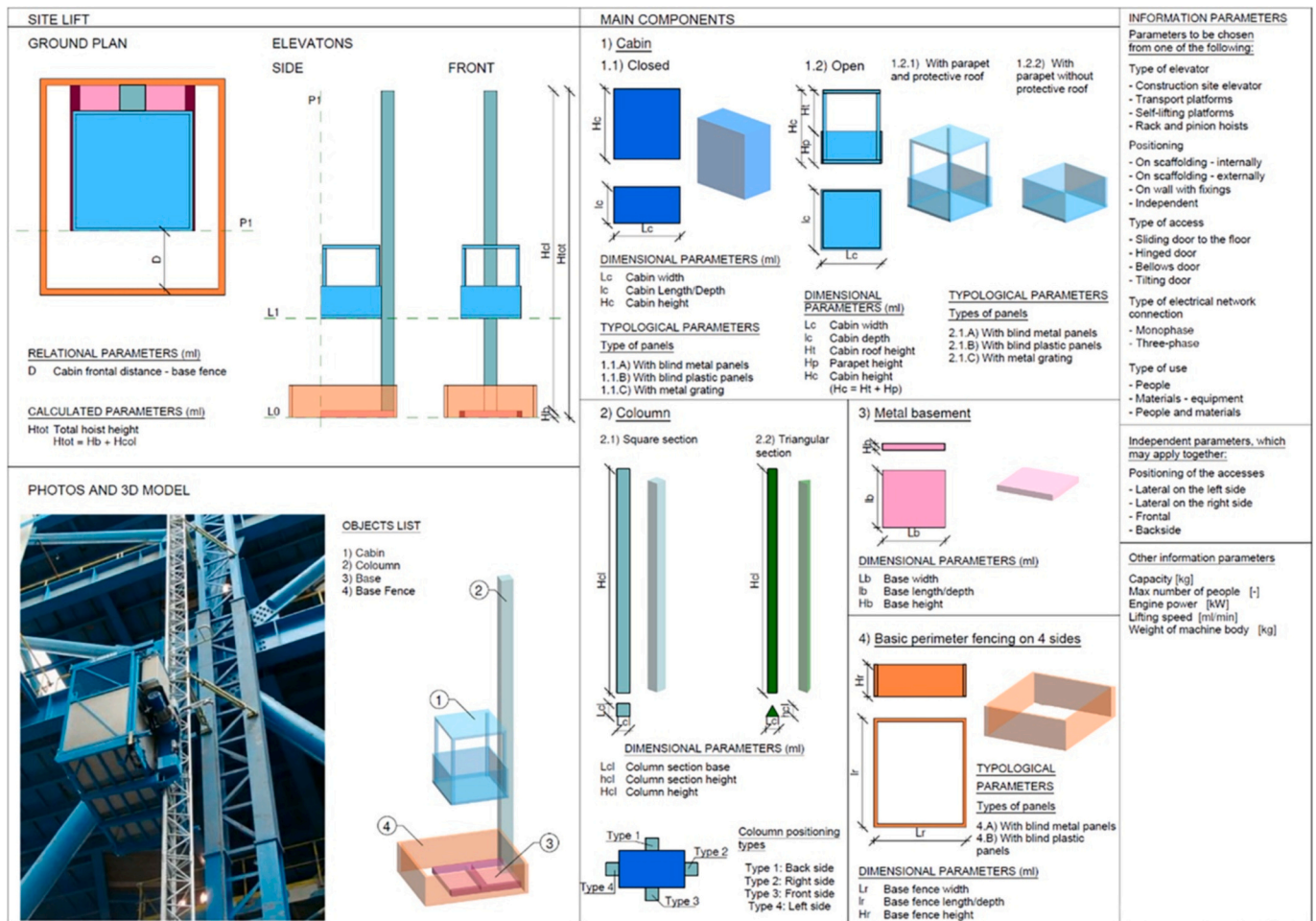


Fig. 14. Site lift – Technical sheet.

ultimately contribute to IFC enhancements or further studies, standardizing the description of these emerging domains in the schema.

Moreover, since the present framework enables different stakeholders to take advantage of an algorithmic and parametric process for collaborative construction site configuration, many operational reworks commonly experienced in traditional client collaboration processes can be avoided. In addition to this, due to the parametric configuration of the developed libraries, the time and economic costs imposed by future possible changes are minimized. Finally, because all the assembly requirements can be embedded in these libraries, the risk of error occurrence in the assembly stage is minimized. Consequently, the need for design and production rework is considerably reduced. Yet, these algorithms work purely on a static basis, i.e., based on the features assigned to the libraries. The authors are currently working on the dynamic variables regarding movements and site object behavior, integrating the library in an agent-based construction site simulator where the site object became a site agent. This paper also proposes further studies to utilize advanced features such as linked-data technologies, Natural Language Processing (NLP), and Large Language Models (LLMs) to capture semantics from automatically various domains and further develop these libraries.

The lack of libraries of parametric BIM objects specific for construction site modeling hinders the timely, accurate, and comprehensive development of BIM models of construction site layouts and activities. To address this limitation and foster BIM-based construction site modeling and simulation processes, an original methodology for developing parametric BIM objects of construction site resources and dedicated libraries with a vendor-neutral approach has been proposed. The feasibility and effectiveness of the proposed methodology have been confirmed through the results of the case study implementation, which involved the development of:

- *A construction site BIM object library* compliant to the Italian national regulatory context, comprising 253 object typologies organized into ten categories and four sections.
- *36 site objects*, from the market analysis to the final production of technical sheets and reports, serving as operational support tools for implementing the related parametric BIM object in different authoring environments.

The methodology is currently being used to develop a parametric library of site objects in the BIM Platform of ACCA Software² (see Appendix A) for use in their BIM authoring environment, specifically targeting safety and construction site management. Future research could build upon this work in several key areas:

- *Support for Construction Safety Code Checking*. Current safety planning approaches, which often rely on text-based, standalone check-sheet tools, could be transformed by integrating BIM-based methods. With the growing adoption of BIM in the construction industry,

standardized site information libraries could enable more efficient safety planning and validation processes. For example, the New York City Department of Buildings (NYC-DOB) has adopted BIM-based workflows to validate construction site safety plans digitally [83]. Leveraging predefined rules for site planning, parametric rule-checking could ensure the consistency and quality of site BIM objects, making it possible to automatically assess compliance with safety codes through BIM-based rule validation.

- *Enhance the development of Immersive Workers safety training*. The proposed site object libraries can significantly contribute to immersive training scenarios using VR/AR technologies. By embedding relevant safety information in digital objects, these libraries can make virtual training more effective for construction workers. Furthermore, the integration of site-specific BIM objects could automate VR-based training workflows, offering cost-effective solutions to train workers through “one-click” VR setups.
- *Enhance the implementation of 4D BIM Construction Site Planning*. Traditional 4D BIM models often exclude key site elements, such as temporary facilities and machinery, which limits their ability to address time-space management needs effectively. By incorporating parametric site objects from this research, future 4D BIM models could offer more comprehensive and realistic representations of construction site activities, helping to resolve some of the inefficiencies observed in earlier studies.

CRediT authorship contribution statement

Vito Getuli: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Alessandro Bruttini:** Writing – original draft, Validation, Project administration, Methodology, Investigation, Conceptualization. **Farzad Rahimian:** Writing – review & editing, Writing – original draft, Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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Appendix A. Appendix

In the following Tables 7–11 the structure of the construction site BIM object library resulted from the case study implementation of the criteria proposed in this paper for the Italian regulatory context is reported. At the current development stage, the library presents 4 sections, 10 categories and 253 object typologies, 36 of which have been implemented according to the proposed construction site BIM object development workflow (see site lift example, Section 7).

² <https://www.acca.it/>

Table 7

Construction site BIM object library (part 1).

Section	Category	Typology		
Construction site organization	Accesses	Driveway access	Two-leaf aluminum blind panel driveway gate	
			Two-leaf driveway gate in electronically coated panels	
			Sliding driveway gate	
		Pedestrian access	Wooden road bar with counterweight	
			Aluminum road barrier with counterweight	
			Single-leaf pedestrian gate in blind panel	
	Barracks	Offices	Single-leaf electrogalvanized panel pedestrian gate	
			Full-height turnstile	
			Tripod turnstile	
		Toilets facilities	Technical Office	
			Construction management office	
			Guarding	
		Storages	Toilets	
			Chemical toilet	
			PPE storage room	
		Storages	Resting rooms	Perishable materials
				Canteen
				Dormitories
	External tanks		Infirmary	
			Changing rooms	
			Flammable/dangerous liquids	
	Construction site machineries	Washing machineries	Mobile water tanks	
			Underground tanks	
			Transportable silos	
		Earth working machineries	Monobloc silos	
			Bolted silos	
			Waste and residue storage	Waste containers/trash containers
		Iron working machineries	Containers for waste collection	
			Waste bins	
			Wheel washing system	
Wood working machineries		Concrete washing system		
		Crushing and screening system		
		Reinforcement bar cutting		
Concrete processing machineries		Reinforcement bar bending machine		
		Reinforcement bar calendrer		
		Cutting table with circular saw		
Construction site installations		Energy generators	Saw bench	
			Concrete mixing system	
			Hydraulic cut-off machine	
	Pumping systems	Generator sets		
		Power generator		
		Mud water collection pumps		
	Miscellaneous machineries	Motor pumps for drainage		
		Vehicle weighbridge system		
		Electrical cabinet		
	Electrical system	Single or multicore red copper cable		
		Insulated copper telephone cables and conductors		
		PVC cable ducts		
Driveways cable ducts				
Reinforced concrete manholes				
Resin manholes				

Table 8

Construction site BIM object library (part 2).

Section	Category	Typology	
Construction site organization	Construction site installations	Lighting system	Light tower on stand Light tower on wheels Steady red light lantern Steady yellow light lantern Yellow flashing light lantern
			Headlamp
			LED bar
			Traffic light system on wheels
			Traffic light system with fixed plastic base
		Grounding system	Earth electrodes (cross, flat round, rope)
			Copper cables
		Lightning protection system	Captors
			Dispersers
		Plumbing	Galvanized steel ducting
			Polypropylene ducting

(continued on next page)

Table 8 (continued)

Section	Category	Typology
		Multilayer pipes Concrete ducts Connections Prefabricated hydraulic manholes with PVC manhole cover Prefabricated hydraulic manholes with reinforced concrete manhole cover Prefabricated hydraulic manholes with reinforced concrete manhole cover Prefabricated concrete channel with gratings ABS channel with gratings Drain grates Domestic hot water boilers Storage tanks (concrete, pvc) above ground Storage tanks (concrete, pvc) underground Imhoff septic tank (concrete, pvc) Bi-chamber septic tank (concrete, pvc) Septic tank three-chamber (concrete, pvc) First rain basin (concrete, pvc) Lining tanks (concrete, pvc) Oil separator sump Degreaser sump Drainage sump Heating and air-conditioning systems Electric fan coil units Electric radiators Orange plastic net with concrete footing Orange plastic net with infilled poles Pipe-and-joint with red plastic net Pipe-and-joint with wooden panels Pipe-and-joint with electro-galvanized panels Pipe-and-joint with trapezoidal sheet metal panels Electro-galvanized panels with concrete base Galvanized iron modular barrier Polyethylene tape Ballasted polyethylene new jersey road barriers Precast concrete new jersey road barriers with electro welded panel fencing in hot-dip galvanized grating Precast concrete new jersey road barriers with aluminum trapezoidal sheet metal fence Noise barrier: anti-noise curtain of sound-absorbing material mounted on existing fence Noise barrier: aluminum clad panel mounted on concrete foundation Noise barrier: aluminum-coated panel mounted on new jersey Noise barrier: transparent polymethylmethacrylate panel mounted on concrete plinth Noise barrier: transparent polymethylmethacrylate panel mounted on new jersey
	Worksite equipment	Fences

Table 9

Construction site BIM object library (part 3).

Section	Category	Typology
Construction site organization	Worksite equipment	Fences Noise barrier: wood panel mounted on concrete plinth Noise barrier: wood panel mounted on new jersey Noise barrier: aluminum panel with self-supporting steel structure Protective screens (welding) Parapet with steel posts and wooden planks Wooden parapet Parapet with tubes and joints Prefabricated steel parapet Wooden planking counter wall supported by piles Metal sheet piling Diaphragms Micropiles Shoring Miscellaneous Construction site notice Prohibition signs Prohibition of access to unauthorized persons Prohibition of smoking and using open flames Prohibition of passing through the working field of a machine Prohibition of extinguishing fires or flames with water Prohibition of depositing materials Prohibition of removing safety devices and guards Irritants and/or harmful Toxic Explosive material High temperature Caution height difference Opening in the ground
Collective protection equipment	Construction site signs	Warning signs

(continued on next page)

Table 9 (continued)

Section	Category	Typology
		Combustible Suspended loads High voltage Danger of excavation Work in progress Falling materials from height Danger of tripping Danger of passing trolleys Scaffolding being set up Vehicle egress Use of mask Use of cap Use of helmet Use of protective shoes Use of gloves Use of protective clothing Use of safety belt Use of goggles Use of protective shield Pedestrians on the right Controlling ropes and chains Walking vehicles Obstacle marking Hazard spot marking Signalization of traffic routes Fall from height Slip Opening in the floor Falling objects from above Interference with other work Burn hazard Electrocutation risk Ballasted bag Road cones
		Obligation signs
		Traffic signs
		Signs for specific hazards
		Other

Table 10

Construction site BIM object library (part 4).

Section	Category	Typology
		Co2 fire extinguishers Powder fire extinguishers Foam extinguishers Wheeled fire extinguisher Fire extinguishing systems Linear smoke detector Alarm button Fire sensor Acoustic detector
	Fire	Fire-fighting equipment
		Emergency exit Collection point Fire extinguisher Fire truck connection Fire alarm Firefighting equipment Prescriptions Communication device Emergency room Infirmary First aid stretcher Emergency eyewash station Emergency shower Prescriptions Covid-19
Emergency management		Signs
		First-aid facilities
	Accident	Signs
		Excavation and loading Wheeled excavator Track excavator Demolition excavator Wheel loader Track loader Scraper Dozers Grader – Motor-grader Bobcat wheeled Bobcat crawler
Machines	Worksite machines	Earthworks
		Excavation and transport

(continued on next page)

Table 10 (continued)

Section	Category	Typology	
			Wheeled mover Telescopic wheeled mover Backhoe loader
		Transport	Articulated wheeled dumper Rigid frame wheeled dumper Tracked dumper Forklift Tanker truck
		Material lifting	Cranes Scaffolding jib cranes Pillar cranes Bridge cranes Gantry crane Self-erecting crane Crawler crane Tower crane Rotating crane truck Truck crane
		Compaction machines	Roller Manual vertical rammer
		Demolition machines	Vibratory plate rammer Hydraulic hammer Telescopic lift
		Lifting machines	Telescopic boom platform Truck with aerial platform Electric hoist Pipelayer
			With flag support Slide with steel stand

Table 11

Construction site BIM object library (part 5).

Section	Category	Typology	
		Equipment and machinery for drilling and boring	Hydraulic drilling machines Micropile machine Rotary machine for drilled piles Rotary drill Rotary-percussion drilling machine
Machines	Worksite machines	Concrete machinery	Injection machinery Concrete mixer truck Concrete mixer Truck-mounted concrete pump Kneading machine
		Maintenance machines	Construction track watering machine
		Vehicles	Truck Car

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