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Analyzing the Level of Detail of Construction Schedule for Enabling Site Logistics Planning (SLP) in the Building Information Modeling (BIM) Environment

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Abstract: As Building Information Modeling (BIM) becomes the predominant technology in the construction industry, contractors, amongst other activities, need to conduct Site Logistics Planning (SLP) in the BIM environment during different project phases. 4D BIM modelling is an important step towards developing BIM models ready for the construction execution phase. However, in developing such models, currently no standard exist which would guide contractors towards a thorough analyses of site logistics. Moreover, there is a scarcity of studies and research on level of detail of construction schedules, which makes SLP hard to implement in a BIM environment. We addressed this problem by employing a case-study method for understanding how 4D BIM models should be designed to enable effective SLP and dynamic site layout creation. The results show that the following input data for SLP in the BIM environment is needed: hierarchically structured 3D BIM model, Work Breakdown Structure (WBS), detail schedule, resources constraints, and defined onsite temporary facilities. Additionally, we have found that the activities should be further divided into work operations to enable SLP. Our results enable contractors to create a dynamic site layout according to the BIM principles. Moreover, the findings are an initial step for the further standardization of the BIM model for the SLP in the BIM environment.

Keywords: Site Logistics Planning (SLP); Building Information Modeling (BIM) environment; level of detail; construction schedule; equipment library; 4D BIM tools

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1. Introduction

The construction industry is project-oriented, resistant to change and unique in its work environment. Furthermore, it is based on geographically dispersed projects, non-integrated supply chains and strong interdependencies between project participants [1–4]. In such complex environment research shows that off-site, on-site, and floor-level logistics costs represent a substantial share of the project total cost, but also that insufficient Site Logistics Planning (SLP) and lack of multi-stakeholder interactions are some of the main reasons for logistics problems [5–7]. Adequate construction site planning reduces transportation and logistics cost, increases productivity and safety, and contribute to sustainability [8]. Thus, SLP and Construction Site Layout Planning (CSLP) are crucial activities for contractors during mobilization and construction project phases [7,9,10].

As Building Information Modeling (BIM) becomes the predominant technology trend in the construction industry, contractors start applying it to usual activities such as SLP. Incorporating BIM in SLP can reduce deliveries on site, waste removal from site, noise pollution, carbon emissions, road congestion, etc., which provide the opportunity to plan more sustainable sites [11–13]. When implementing BIM, contractors usually use two BIM implementation strategies, which can be either in-house BIM implementation by training current staff or outsourcing BIM to specialized Information Technology (IT) companies [14].

In doing so, SLP is a BIM functional area which contractors usually perform within the organization, as well as scheduling [14]. This only brings more complexity to the process of 4D modelling, especially as contractors are often required to provide 4D BIM model before starting the execution of construction [15].

When starting with SLP in the BIM environment, the specifications of three key requirements for SLP should be defined. Requirements are the BIM tool for SLP, the type of resources that are to be considered and the organization of the BIM model, which will enable site logistics analyses. Currently there are vast areas of research which have been analysing the requirements for SLP in the BIM environment (Figure 1) and in the next three sections we will summarize the influence of the mentioned requirements on the SLP.

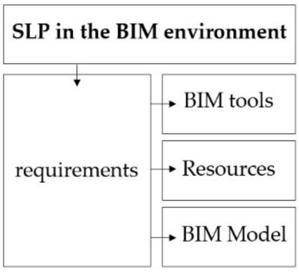


Figure 1. Requirements for SLP in the BIM environment.

1.1. BIM Tools for SLP

BIM tools that enable SLP fall into two categories—3D BIM (e.g., Revit, Allplan, Tekla) and 4D BIM tools (e.g., Synchro 4D, Vico Office, Navisworks, Bexel Manager, Tekla BIMsight, Infra Works) [16–20]. 3D BIM software enables creation of the static layout models, which assume that all components (e.g., equipment, temporary facilities) of the BIM model exist through the entire duration of the construction and that all components have a fixed position on the construction site [21]. Thus, 3D BIM tools have limited functions for supply chain analysis due to the inability to link construction schedule activities with elements of the BIM model [22,23]. Static layout models are created using available object libraries (e.g., equipment libraries, libraries of temporary facilities), from which BIM site objects are imported in a 3D BIM model [17,22,24].

Furthermore, 4D BIM software can be dived into two categories—construction planning and site planning [22]. 4D BIM software for construction planning include functions for: construction activities analyses and duration estimation [25]; construction schedule definition; schedule optimization; resources management and allocation; resources utilization calculation; workspace planning [22]; construction monitoring; as-built schedule management [26]; safety planning; labour evacuation planning [27]; tact-time calculation [28]; and the visualization of project construction (considering only the building elements defined by the designer in the 3D BIM model using BIM authorization software) [29].

4D BIM software for site planning enables creation of the dynamic layout models which consider the actual duration for which temporary facilities and equipment are required on the construction site during different phases of construction [8,10]. Additionally, dynamic layout models integrate the construction schedule and 3D model data based on scope quantification, supply chain management, storage space analyses and workspace conflict detection [10,30–32]. During dynamic layout model development, the interrelationship between supply points allocation and machinery location should be examined [33]. 4D BIM tools for site planning have functionalities for: the inspection of workflow (4D) clashes (clashes of contractor scheduling, equipment and material delivery, workflow, and workspace conflicts) [34–36]; managing site logistics (including tower cranes, restricted areas, scaffolding, transport routes, etc.) [22,37]; the calculation of storage and accommodation capacities [38–40]; supply chain visualization [41]; resource management including planning, organization, coordination, and control of site activities [42]; safety planning and analyses [43,44]; off-site and on-site logistics coordination [45]; and suppliers and subcontractors coordination [45].

Since the functionalities of individual BIM software solutions are limited, other Information and Communication Technology (ICT) has been adopted for SLP [46] and integrated with BIM software [47,48]. The basic functionalities of the software can be extended by programming a software add-on using the Application Programming Interface (API) of specific software (e.g., an add-on for the automatic creation of site layout [21]; an add-on for automatic site layout verification [17]). As BIM tools lack specific analyses important for SLP (e.g., geospatial analyses), BIM solutions are often integrated with other systems to provide more robust solutions for SLP. Thus, BIM systems have been integrated with: Geographic Information Systems (GIS) to reduce transport costs, provide more accurate material delivery to construction site and flexible site layout [49–52]; systems for Virtual Reality (VR) to visualize the construction site in real time and identify errors during the execution phase [53,54]; barcodes (Quick Response—QR) to obtain data about worker and their training, define their daily activities on the site, etc. [55]; Radio Frequency Identification (RFID) systems to achieve information visibility during material coordination [56] and equipment positioning [57]; Global Positioning Systems (GPS) to reduce storage space on the construction site, to better manage procurement and reduce material procurement costs [58,59]; and the concept of videography through a low-cost Internet Protocol (IP) camera and Matrix Laboratory (MATLAB) for the image processing of the as-build quantities of construction activities [60].

Therefore, BIM tools enable solving SLP and CSLP problems in a BIM environment, which have vast advantages in comparison with traditional way of solving such problems. Some of advantages of using BIM for logistics management are: better conflicts analyses and logistic coordination; connecting safety more closely to construction planning, producing 3D site layouts; connecting scheduling and site planning; the visualization of supply chains and the construction of the project; the identification of available space for storage and transportation [6,10,19,34,61].

However, there is a lack of knowledge about standardized SLP in the BIM environment, which implies a non-standardized level of development for the 3D BIM model, temporal facilities, equipment libraries, schedules, etc. Moreover, there are currently a lot of problems when using BIM tools for SLP and CSLP: staff in contractor construction companies (e.g., site planners, site managers) lack the competence to use BIM software tools [62,63]; there is lack of collaboration between designers and contractors when defining 3D BIM models [34,62,63]; information provided by 3D BIM models is incomplete for scheduling and difficult to extend using the Industry Foundation Classes (IFC) standard [29]; components provided in the 3D BIM models are difficult to connect with schedule activities [29,63,64]; 4D BIM tools do not offer effective time management because the 3D visualization of construction has mainly been focused on [65]; defining model specification and connecting 3D BIM elements with schedule activities is a time-consuming process [34,65]; previous studies did not focus on the detailed short-term (the planning of non-completed work) and middle-term or on look-ahead (the planning of internal site logistics) planning in a BIM environment, which is crucial for construction and resources planning [66].

To sum up, in this subsection we analysed BIM tools, which can be used for SLP. Analysis shows that 3D BIM software are adequate for SLP only in pre-design and design phases as they only enable static layout model development (Figure 2). On the other hand, 4D BIM software for site planning are the best option for mobilization and construction phases due to functionalities which enable dynamic site layout development (Figure 2).

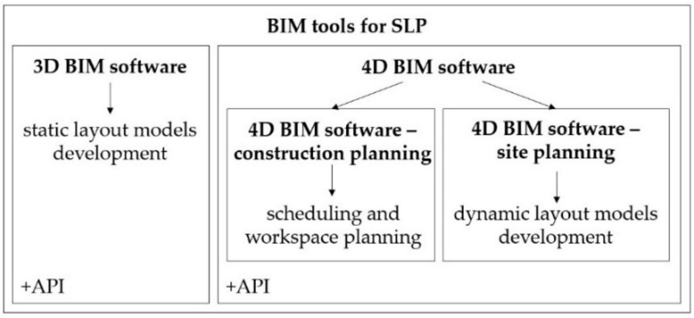


Figure 2. BIM tools for SLP.

1.2. Simulation of Different Type of Resources in the BIM Environment

Resources management includes planning, organization, and the coordination and control of materials, machinery, construction equipment, temporary facilities, workspace, storage space, location, and labour resources [67–70]. In this paper, the word *machinery* signifies tools (machines), which are used to operate specific activity, while the word *equipment* indicates all necessary items needed on the construction site.

Building elements (materials) should be examined along five stages, which are procurement, stockpiling, handling, provision, and laying [71]. BIM tools can be used for solving the problems associated with material management (e.g., problems related to the on-site logistics problems but also to the material purchasing and supply) [72]. Building elements could be associated with construction schedule activities, which enables the simulation of construction. In doing so, the most important thing is the Level of Development (LOD) of the BIM model. LOD 400 is crucial for daily work orders visualization, while LOD 300 does not provide all necessary corresponding elements in the BIM model (e.g., reinforcing bar objects) [73–75]. There are also possibilities for the extraction of Quantity Take-Off (QTO) and the Bill of Materials (BOM) from a BIM model, which are also valuable pieces of information for the analyses of material handling on the construction site [76]. Further, for the calculation of the volume of excavated soil, it is necessary to model the excavation pit, which consists of a ground model (surrounding terrain), void elements (depth of excavation pit), and bordering elements (cutting edges to represent pit walls) [61].

Furthermore, in the BIM environment, there is a lack of the systematic integration of temporary structures in BIM models (e.g., scaffolding, formwork, temporary facilities, equipment, machinery). Lists of the requirements for the description of the site elements are accessibility, a stay on site area, installation, usability, and productivity [71]. Currently, temporary structures are manually embedded in the BIM model through equipment libraries, temporary facilities libraries, or other type of object libraries [19,24,68] or from other software packages where they can be manually designed (e.g., Sketchup) [8]. Datasets (attributes, descriptions, information, etc.) of BIM objects in such libraries are often unstructured and allow only a more realistic construction visualization [10,68]. Researchers have also been developing approaches for the optimal temporary structures positioning on the construction site [47,48,70]. To reduce the manual planning of temporary facilities, many authors have explored frameworks for the automatic generation of site layout and temporary structure plans (e.g., scaffolding plan [68], formwork plan [74], and temporary facilities plan [52]). Moreover, machinery management based on BIM environments should enable machinery location selection, type and configuration selection, motion planning, and lift modelling [21,77,78]. Motion and lift planning involve modelling the trajectories and lift paths [79] for machinery and cargo, which provides indispensable dynamic collision detection (e.g., the intersection of machinery, interaction between temporary facilities and machinery, space occupation) [42,77,80]. Finally, workers could also be manually embedded into the BIM model as objects through the object data library. Trajectories modelling provides crew coordination and enables safety planning and potential safety hazard identification [68,81,82].

The critical characteristics of the construction site area are available spaces, surface features, aerial restrictions, soil and underground features, and interference with other activities [71]. Nowadays, space is a deficient resource and needs to be examined through the project schedule. On the one hand, inadequate space planning and transportation management may cause a waste of space and inadequate transportation distances planning [11], but, on the other hand, workspace could be too crowded for productive work [83]. Workspace management in a BIM environment includes workspace classification, workspace generation and representation, and workspace conflict identification [67,84]. When analysing spatial constraints, there are differences between direct and indirect workspace. Direct workspaces include entity (object), space (physical volume of the space occupied by laborers, equipment, or components), construction working space (space which enables the movement of entities when performing certain activities), and storage space (area for stocking materials), while indirect workspace includes setup space, path space, and unavailable space [26,67,84]. Construction workspace is further dived into safety working space and efficient working space [26]. Workspace can also be classified by movability on fixed and flexible workspace [84]. In a BIM environment, workspace can be generated by using the bounding box model [26], simplified 3D models of geometric containers (e.g., parallelepiped), or parametric 3D models with descriptions [67], but activity workspace modelling requires the visualization of all construction entities that are needed during construction activity execution on the site [85]. Thus, 4D BIM tools enable the analyses of flexible workspace according to the construction schedule because they can simulate the changes of the working space through workspace evolution patterns (e.g., evolution patterns for the concrete works are mostly preparation, concreting, curing, and formwork stripping) [83]. Such defining of space enables workflow clash detection, time–space conflicts identification, and spatial–temporal hazard investigation and safety information investigation [18,84,85].

Information about resources could be included in the BIM model using specific attributes or property sets, according to the IFC schema [86]. Such information could be assigned to specific BIM objects. For example, LOD 300 enables the parametric estimation of material quantities using the relationship between *IfcProduct* (3D object) and *IfcRelUsesResource* (material quantity information) [69]. Furthermore, attributes for workforce planning could be added to the BIM object (e.g., skill type, supervision level, certification) [87] or other information (e.g., RFID tags) could be assigned to the BIM object using *IfcRelAssign* [88]. Although there are developed IFC classes for construction management domains [89], a lot of classes are missing and IFC schema should be extended to represent construction elements in a BIM environment [90]. Thus, construction site BIM objects could be manually mapped with the *IfcBuildingElementProxy* entity and identified by using property-based identifiers [61]. Possibilities of resource type simulation in the 4D BIM environment are summarized and shown in Table 1.

Table 1. Simulation of different resource types in the BIM environment.

Resource Type	Simulation in the BIM Environment
Material	3D BIM model LOD 400; BIM model, QTO and BOM integration; excavation pit; *IfcRelUsesResource*
Temporary facilities	BIM objects; *IfcBuildingElementProxy*
Equipment	BIM objects; *IfcBuildingElementProxy*
Machinery	BIM objects; *IfcBuildingElementProxy*
Workers	BIM objects; *IfcBuildingElementProxy; IfcRelAssign*
Workspace	bounding box model; simplified 3D models of geometric containers; parametric 3D models with descriptions

1.3. Structure and Dataset of the BIM Model for SLP

SLP is activity which is carried out during different project phases. Construction site pre-design is activity which is carried out by a designer during the early phases of the project (until tender) with less detail and basic information about the location of temporary facilities on the construction site [91]. On the other hand, construction site execution-design is carried out by the general contractor and subcontractors from tender response until the end of construction and is much more detailed with the selected type of equipment, location of temporary objects, etc. [49,91,92]. According to Caldart and Scheer [8], SLP processes can be divided into three stages that are connected with the specific project phase: attack plan (definition of activities sequences and deadlines and resources for task execution); macro transport logistics (internal logistics analyses); and construction site design (placement of temporary facilities and storage of materials). In addition, Bortolini et al. [20] divided logistics planning and control in different hierarchical levels: long-term logistics plan development (including architectural design developed in the LOD 200, inventory areas definition, equipment selection, temporary facilities definition, pedestrian routes definition); batch logistics plan development (including detailed structural design developed in the LOD 350, inventory areas for the process, equipment used in the process, pedestrian routes definition); and logistics control execution (including the inspection and analysis of the logistics plan on the site).

Except site layout modelling, increasing the detail of information through the project progress affects the 3D modelling process and the scheduling process as well. Currently, different organizations define different naming conventions for describing the level of detail of the 3D BIM models in terms of graphical representation and defined attributes. Terms which have been used are *Level of Detail* (LOD), *Level of Geometry* (LOG), *Level of Information* (LOI), *Level of Model Definition* (LOMD 1–LOMD 7), *Level of Development* (LOD 100–LOD 500), *Level of Development of the Object* (LOD A–LOD G), and *Level of Information Needed* (LOIN) [24,69,93,94]. The problem of LOD definition is reflected in the quality of clash detection performed using a federated model (includes the architectural model, MEP model, etc.). If each of these models is designed in different LOD and does not contain all the necessary information, the clash detection may not show accurate results [24]. Not clearly defined 3D model execution plans (which include 3D model attribution standardization, naming conventions, etc.) and the fact that the engineering part does not perceive 3D models as project deliverables cause discrepancies between the information provided in the engineering deliverables and the information needed by construction part [63]. Due to a lack of collaboration between designers and contractors when defining 3D BIM models, site managers spend a lot of time on the analyses of BIM models and distribute the missing information to other project participants [62]. Thus, 3D models should be explicitly defined as deliverables in contracts (change conventional contract cultures), and 3D model execution plan (including LOD specification, for model elements, attributes, needed information, etc.) should be defined in the early phases of the project, while all project participants should be included in this process [63].

When analyzing resources in the BIM environment, it is very important to differentiate between BIM elements (part of building) and BIM resources (3D objects of site equipment). The geometry of site elements does not need to be as detailed as the elements of the building (Figure 3) [61,75].

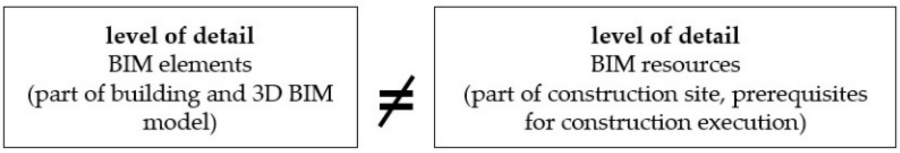


Figure 3. Difference between level of detail—3D BIM model and BIM resources.

In project phases until the tender response, building elements need to be developed in the LOD 200, while during further phases building models need to be developed in the LOD 350 or 400 to enable SLP [20,73,75]. On the contrary, there is no standard for the definition of LOD for site elements, which is why the client should specify their information requirements in detail [71]. Cassano and Trani [24] define the levels of information discretization for construction elements: an element sheet for installation (LOD 400), an element sheet for the developed and detailed level of detail (LOD 300/350), and an element sheet for the draft level of detail (LOD 200). Furthermore, site elements are often not included in the initial BIM model defined by the designer, but they are imported in a 4D BIM model from equipment libraries. In doing so, the changing of LOD, LOI, etc., is impossible after element import but rotation, translation, and scaling are possible [17,21]. Product libraries are growing rapidly on the World Wide Web (WWW), but the BIM objects in such libraries are usually from heterogenous systems, various manufacturers, and have non-standardized product descriptions (ambiguous expressions and attributes, uncertain categories and levels of development, etc.). Thus, it is very difficult to find useful and adequate BIM resources [66,95,96].

When analyzing the scheduling process and creating a 4D BIM model, the problem of producing information on different levels of detail (in stages from general to detailed levels [97]) becomes more complex because the level of detail in the construction schedule is also not standardized. In doing so, it is necessary to differentiate between the production planning and construction planning. Production planning includes the development of factory and plant layouts, factory flows and movement simulation, etc. [75], and is too detailed for application when developing dynamic construction site layout. Additionally, it is important to differentiate between [17,21,75,97]:

- Construction schedule and 4D BIM model developed only for building elements (without site objects);
- Construction schedule and 4D BIM model, which include site elements without their dynamic movements—static layout models;
- Construction schedule and 4D BIM model, which include site elements with their dynamic movements—dynamic layout models.

There are more terms which try to define the level of detail in a construction schedule. First is the level of planning, which differs in the long-term (e.g., defining the flow of components, storage areas, position of equipment), look-ahead (e.g., access to storage areas, location of temporary facilities, vehicle traffic routes), and short-term (e.g., feedback concerned with the site layout, flow of components, storage areas, position of equipment) planning [20,98]. Second is Level of Project Planning (LOP), based on LOD, with stand-out listed levels: LOP-000 (only key milestones), LOP-100 (executive summary with rough estimations of durations), LOP-200 (management summary with the first global 4D visualization of site logistics), LOP-300 (project coordination with resources assignment), LOP-400 (the execution level, which is drawn up in phases and resources are planned in detail), and LOP-500 (as-build planning—updated LOP-400) [99]. Third is the 4D scheduling concept defined by United States General Service Administration (GSA), which includes LOD 100 (phasing of major elements), LOD 200 (the appearance of major activities), LOD 300 (appearance of detailed assemblies), and LOD 400 (definition of fabrication and assembly details) [100]. The fourth definition is the level of detail in Location Breakdown Structures (LBS), which influence the planning method because LBS enables the granular mapping of data related to levels, zones, phases, rooms, assemblies, etc. [64]. The fifth definition is temporal LOD, which some authors differ from graphical LOD [101,102]. All mentioned concepts are listed and compared in the Table 2.

Table 2. Concepts which define the level of detail of the construction schedule.

No	Concept Name	Level Name	Description
1	Level of Planning [20,98]	long-term plan look-ahead plan short-term plan	planning of overall logistics planning of internal site logistics site plan control and planning of non-completion work
2	Level of Project Planning (LOP) [99]	LOP-000 LOP-100 LOP-200 LOP-300 LOP-400 LOP-500	only key milestones executive summary management summary project coordination execution level as-build planning
3	4D Scheduling [100]	LOD 100 LOD 200 LOD 300 LOD 400	phasing of major elements appearance of major activities appearance of detailed assemblies definition of fabrication and assembly details
4	Level of Detail in Location Breakdown Structure (LBS) [64]	-	-
5	Temporal LOD [101,102]	-	-

Accordingly, level of detail has not the same meaning in the 3D BIM model and 4D BIM model, where the biggest problem is when the level of detail in the 3D model, site logistics layout, and construction schedule are not the same (activity can match no BIM objects, part of a BIM object, exactly one BIM object, exactly several BIM objects, several BIM objects, and parts of BIM objects) [101,102]. Planning and scheduling require a clear definition of the project's scope, which should be broken down using hierarchical breakdown structure. Therefore, Work Breakdown Structure (WBS) enables the clear definition of activities in a schedule, which is why WBS has been the most used tool in traditional scheduling for hierarchical planning. When using 4D BIM, organizing data around work location (zones, phases, rooms, assemblies, levels, etc.) proved a valuable method of data grouping. LBS also enable mapping between the BIM elements defined in 3D model and scheduled activities but also the calculation of quantities and costs for each level of grouping [64]. Excepting LOD definition, the problem in creating 4D BIM model is that the information which is provided by the 3D BIM model are often incomplete for scheduling and assigning activities and are difficult to extend using the IFC standard [29,103].

In this subsection we have analysed the problems connected to the structure and datasets of the BIM model, which enable SLP in the BIM environment. The literature review results can be summarized as follows (Table 3):

- Regarding the level of detail of a 3D BIM model, resources and schedule change progressively from more general to more detailed during different project phases;
- Few different concepts define the level of detail of the 3D BIM model (each concept defines a different number of levels, but requirements for each level are quite clearly defined);
- The concepts which define the level of detail of the 3D BIM model are not clearly connected with the requirements for SLP during different project phases;
- There is no specific concept which defines the level of detail of BIM resources (materials, temporary facilities, equipment, machinery, workers, workspace) for SLP in the BIM environment during different project phases;
- Few different concepts define the level of detail of the construction schedule (each concept defines a different number of levels, but the requirements for each level are neither clearly defined nor clearly connected with requirements for SLP during different project phases).

Table 3. Scope of the level of detailed definition through the project's progress, which enables SLP in the BIM environment.

No	Project Phase	LOD Specification
1	Pre-design and design	LOD—3D BIM model LOD—resources LOD—schedule
2	Tender response	LOD—3D BIM model LOD—resources LOD—schedule
3	Mobilization	LOD—3D BIM model LOD—resources LOD—schedule
4	Construction	LOD—3D BIM model LOD—resources LOD—schedule

1.4. Problem, Aims, and Outline of the Paper

The current literature is largely intended for possible users and not for actual ones because many authors analyze the advantages of 4D BIM usage in the site planning domain without moving towards a standardization of dataset for site analyses in the BIM environment [17,62,95]. Furthermore, current concepts which analyse the level of detail of a construction schedule are not clearly connected with the requirements for SLP during different project phases.

Therefore, the research problem was that, currently, no standard exists, which would support scheduling (the level of detail) for enabling SLP in the BIM environment. First, this paper aims to define the level of detail for a construction schedule, which enables the simulation of machinery movement and material handling when developing a dynamic site layout in 4D BIM tools for site planning during the mobilization phase (Table 4). Second, the paper sets out to define the information needed for 4D BIM models, which enables the creation of the dynamic site layout and steps for SLP in the BIM environment (focusing on the mobilization phase and the simulation of machinery and materials). By solving this problem, we would create the initial step for the further standardization of BIM models for SLP.

Table 4. Related studies categorization and scope of research definition (marked as gray).

Requirements for SLP	Description		Related Studies
BIM tools	3D		[17,21–24]
	4D (construction planning)		[22,25–29]
	4D (site planning)		[8,10,22,30–45]
	Add-on API and software integration		[17,21,46–60]
Resources	Workspace		[11,18,26,67,71,83–85]
	Equipment		[8,10,19,24,47,48,52,61,68,70,71,74,89,90]
	Machinery		[21,42,61,77–80,89,90]
	Materials		[61,69,71–75]
	Workers		[27,43,44,68,81,82,87,88]
BIM model	Pre-design and design	LOD—3D BIM model	[20,24,62,63,69,93,94]
		LOD—resources	[17,21,24,61,66,71,75,95,96]
		LOD—schedule	[20,64,97–102]
	Tender response	LOD—3D BIM model	[20,24,62,63,69,93,94]
		LOD—resources	[17,21,24,61,66,71,75,95,96]
		LOD—schedule	[20,64,97–102]
	Mobilization	LOD—3D BIM model	[20,24,62,63,69,93,94]
		LOD—resources	[17,21,24,61,66,71,75,95,96]
		LOD—schedule	[20,64,97–102]
	Construction	LOD—3D BIM model	[20,24,62,63,69,93,94]
		LOD—resources	[17,21,24,61,66,71,75,95,96]
		LOD—schedule	[20,64,97–102]

In doing so, this paper is organized into several sections. In the next section (Section 2) the methodology of the research is presented. Results of the research are presented in the section three (Section 3). Section four (Section 4) brings discussion, while in the final section (Section 5) we provide conclusions, research limitations, and steps for further research.

2. Materials and Methods

For this research we used the case study method to understand how 4D BIM model should be prepared to enable site logistics planning and dynamic site layout creation during the mobilization phase. Case study research is a suitable method for understanding the complexity of the problem connected with the lack of standardization when using BIM tools for site logistics planning. Research was conducted in the following three steps:

1. Material (input project documentation) analyses;
2. Development of the 4D BIM model (including dynamic site layout);
3. Analysis of the results and the definition of the framework for the further standardization of the level of detail in a construction schedule for site logistics planning.

The project selected for this case study was the production hall in Kutina, a city in Croatia. The hall area was 1625 m^2, while the construction site area was 6000 m^2. Furthermore, the production hall was divided into three functional areas—offices, production plant, and warehouse—and consisted of monolithic reinforced concrete parts, prefabricated steel construction, panels (roof and facade), and a drywall system. The preparation for construction works included four activities: 3D BIM model design; WBS; detailed construction schedule development; and construction site equipment definition. Thus, the 3D BIM model, WBS, detail construction schedule, and resources constraints were the input materials for site logistics planning in the BIM environment and needed to be analyzed before starting with 4D modeling and site planning. One of the researchers, as the civil and site engineer, had full access to the project data and participated in developing of all mentioned input data as well as further site layout development.

The 3D BIM model was designed in the BIM authoring software Nemetschek Allplan [104] (Figure 4). Data in 3D BIM model were segregated as follows:

- Project—production hall;
- Buildings—offices, production plant, warehouse;
- Floors—foundations, ground floor, first floor, and roof (offices); foundations, ground floor, and roof (production plant and warehouse);
- Construction elements—slab foundations, steel columns, steel beams, L-profile facade panels, roof frame rafter, roof purlin, roof bracing, and roof panels (offices, production plant, and warehouse); slab, stairs, and partition walls (offices).

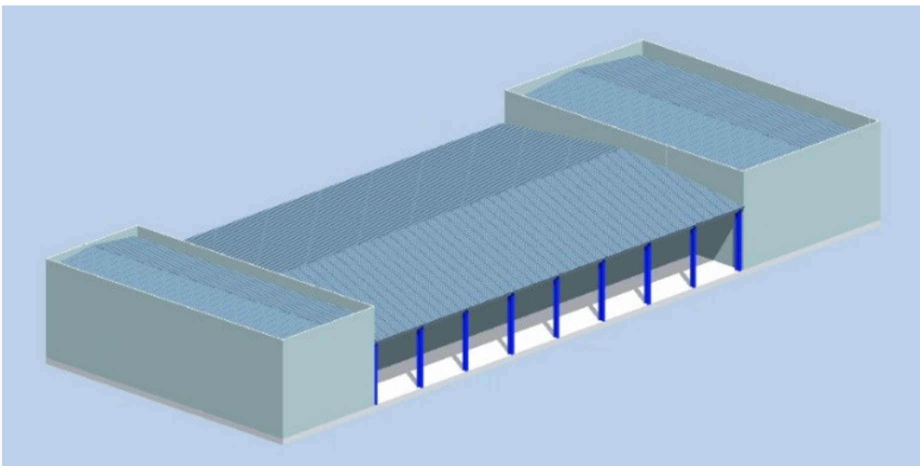


Figure 4. 3D model of production hall.

WBS (Table S1 in Supplementary Materials) was used to divide the project's scope into manageable parts. WBS was developed at six levels, which were in line with the data segregation in the 3D BIM model:

1. Level 1 (red)—project;
2. Level 2 (blue)—work type;
3. Level 3 (yellow)—groups of works (site preparation works and site demobilization works) and building (construction works);
4. Level 4 (green)– floor;
5. Level 5 (orange)—construction element;
6. Level 6 (no color)—activities.

Activities for construction schedule development were defined in the last level of the WBS. Material delivery activities were scheduled at the beginning so as not to affect the construction works. Each activity had an associated duration, predecessor, and successor (Figure 5). The duration of activities was estimated based on the construction company's internal productivity data, while the predecessors and successors of activities were established based on the activities' interdependencies. The estimated duration of site preparation, construction, and site demobilization works was 60 days (Figure 5, Table S1). A detailed construction schedule was developed using the software Bentley Synchro PRO [105], where a Gant chart defines overall time frame for the entire project and enables critical path definition.

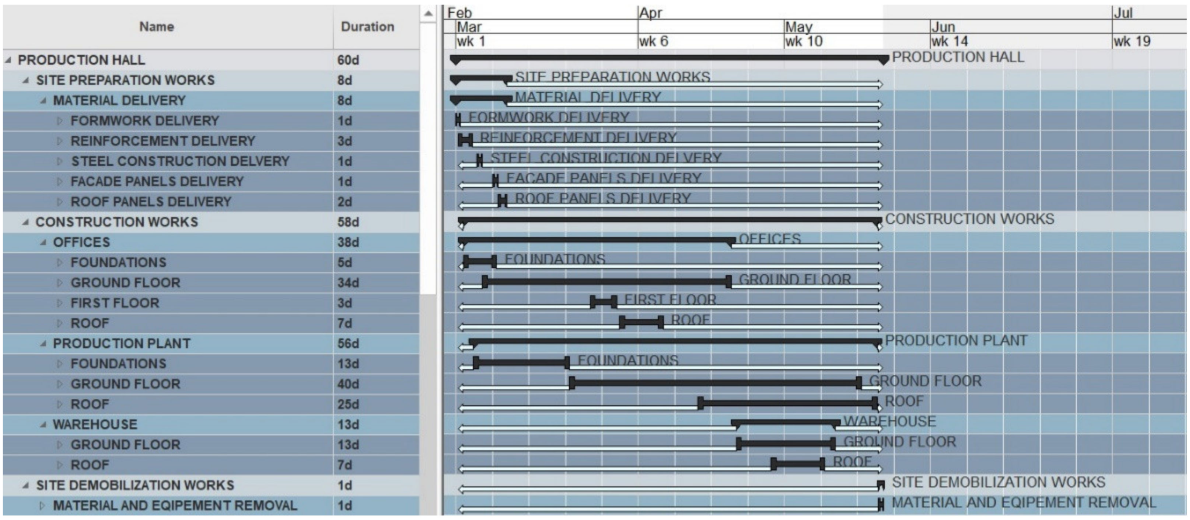


Figure 5. Detailed construction schedule.

To define preconditions for dynamic SLP (specifically machinery movement and material handling), temporary facilities and storage spaces were analysed. Access to the construction site was provided by the existing road, while on the construction site internal traffic routes for machinery operating on the construction site were planned. Necessary temporary facilities were security huts, concrete barrier, security fencing, toilets, and site cabins, while necessary onsite storage spaces were for the storage of formwork, reinforcement, parts of the steel construction, facade panels, and roof panels. Internal traffic routes, temporary facilities, and storage spaces needed to have fixed position during construction execution and needed to stay on the construction site until the end of the construction works. Temporary facilities and traffic routes needed to be presented in their real sizes according to the standard specification for each object. The size for storage spaces was calculated according to the general guidelines for site planning used in the Croatian market [106].

3. Results

According to the input information available in the project documentation, in this research, a dynamic site layout was developed through the three steps: temporary facilities and storage spaces placement (to set the preconditions for dynamic SLP), schedule definition for site logistics planning in the BIM environment and resources assignment, and 4D modeling and dynamic site layout extraction.

3.1. Temporary Facilities and Storage Spaces Placement

Necessary temporary facilities and storage spaces were placed on the construction site according to the general guidelines for site planning used in the Croatian market [106]. Temporary facilities (security huts, concrete barrier, security fencing, toilets, and site cabins) were positioned to remain stationary until construction works completion. Toilets and site cabins were provided at readily accessible places. Internal traffic routes (including machinery stations) were centrally positioned at the site to reduce the distance from the storage spaces to the place of installation. Storage spaces (for the storage of formwork, reinforcement, parts of steel constructions, facade panels, and roof panels) were placed near internal traffic routs. The storage spaces were sized to place all the amount of required material, avoiding any need for changes of storage spaces during construction. Temporary facilities and storage spaces were disassembled after the completion of construction works (during site demobilization). All site elements were imported in Synchro software from the Synchro equipment library [107]. Imported objects were not parameterized, having solely a representative purpose. Objects were displayed in actual sizes and, as such, the visualization and positioning in physical space were relevant for space occupation analyses. Preconditions for further site planning is shown in Figure 6.

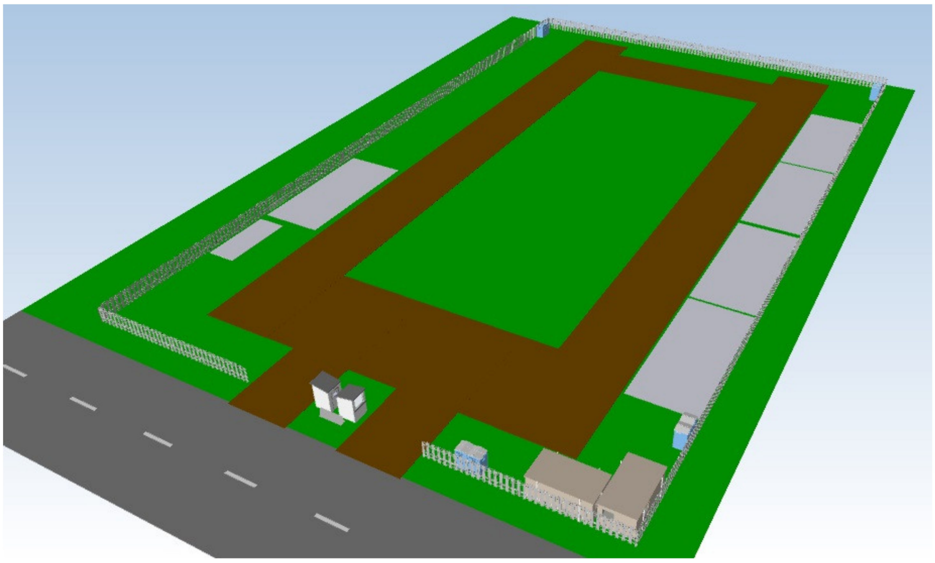


Figure 6. Positions of temporary facilities and storage spaces on the construction site—preconditions for dynamic SLP.

3.2. Schedule Definition for Site Logistics Planning in the BIM Environment and Resources Assignment

A detailed construction schedule for site logistics planning in the BIM environment was developed based on the detailed schedule for the construction phase (Table S1, Figure 5). Defined activities in the detailed schedule for the construction phase were divided into more detail to enable machinery and activities assignment to 3D paths (the trajectories of machinery movement) but also the material handling simulation on the construction site. In other words, each activity defines one work operation (gray color in Table S2 in Supplementary Materials). The duration of activities was estimated based on the construction company's internal productivity data, while the predecessors and successors of activities were established based on the activities' interdependencies.

In parallel with defining work operations, the need for resources was also planned in accordance with the internal productivity data. The organization of work showed that the following machinery was needed:

- Truck for material delivery and removal;
- Forklift for material loading, unloading, and horizontal transportation of materials;
- Truck mixer for concrete delivery;
- Mobile crane for the vertical transportation of materials;
- Truck concrete pump for the vertical and horizontal transportation of concrete.

All machinery model elements (truck, forklift, truck mixer, mobile crane, truck concrete pump) were imported into the Synchro software from the Synchro equipment library [107]. Imported objects were not parameterized, having solely a representative purpose. Objects were displayed in actual sizes, and such visualization and positioning in a physical space were relevant for space occupation and conflict analyses but also on-site logistics coordination.

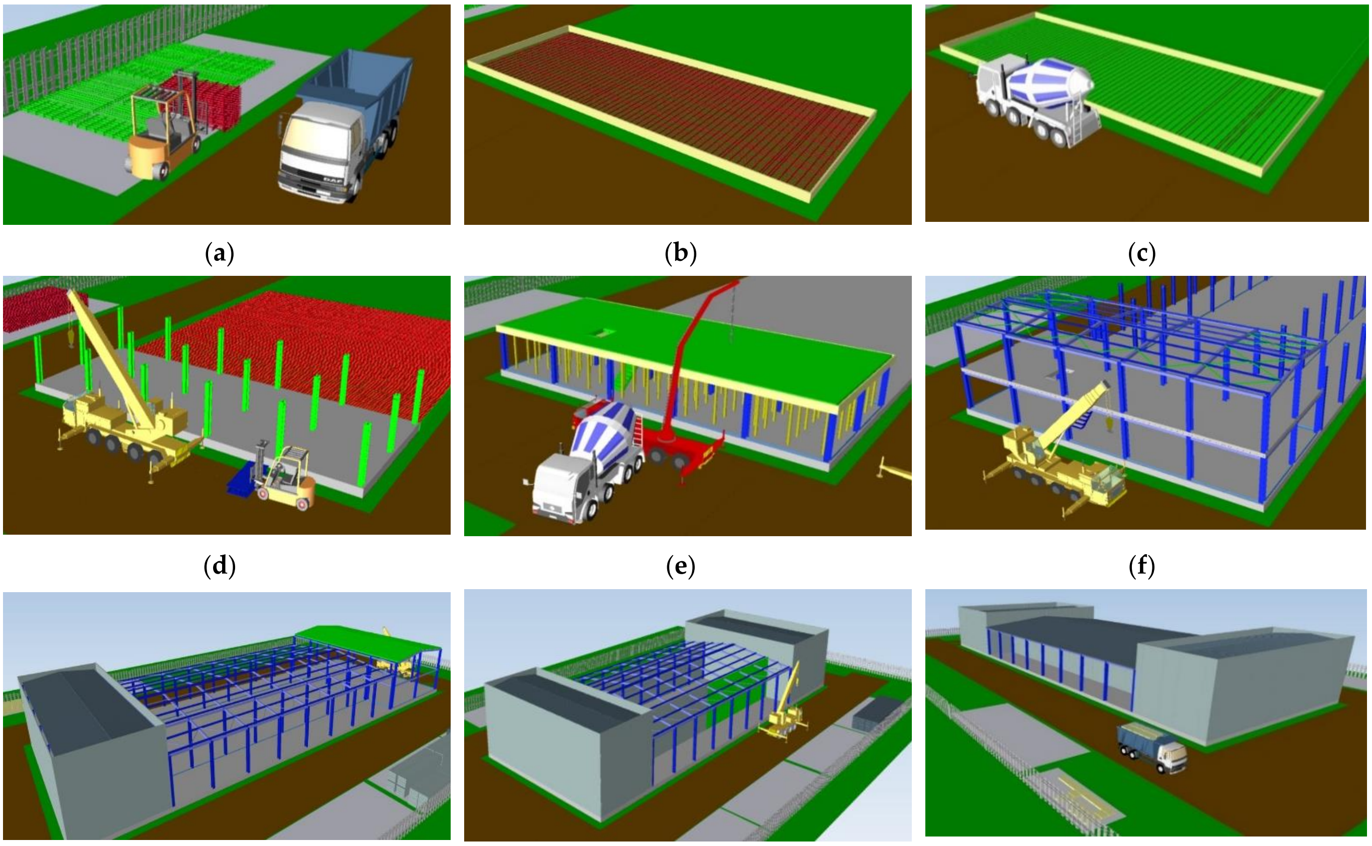
Material analyses was based on the 3D BIM model LOD 400, while material stock was shown using different (added) objects in the stock position. Materials, which were displayed in the stock, were formwork, reinforcement, parts of steel constructions, facade panels, and roof panels, while materials needed for partition walls installation were delivered using the just-in-time inventory management method.

3.3. 4D BIM Modeling and Dynamic Site Layout Extraction

During the third step, 3D BIM elements of the production hall which were built during a specific activity execution were assigned to the appropriate activities in a detailed construction schedule for site logistics planning. Besides the 3D BIM elements of the production hall, the material resources and machinery, which were utilized during the execution of the specific activities, were also assigned to activities. The assignment of materials and machinery is shown in Table S2.

When simulating the construction of elements, material handling, and machinery movements, additional properties and settings were implemented (appearance profile and growth simulation). Elements whose construction was in progress were highlighted with the color green, but when activity was finished all assigned elements appeared in the real colors. Growth simulation depended on the specific element (e.g., growth simulation for a slab is left to right). Furthermore, the start and active appearance of materials depended on the material type (blue for formwork, steel construction, and panels; red for reinforcement), while the end appearance was the original color. Finally, to define the trajectories of the movement of materials and machinery, 3D paths were defined and specific activities and resources were assigned to them. When resource and activity were assigned to the 3D path, specific resource changed position according to the 3D path line during activity execution.

The result of third step is the dynamic site layout or 4D simulation of the site logistics on the construction site (Figure 7).



(**a**) (**b**) (**c**)
(**d**) (**e**) (**f**)
(**g**) (**h**) (**i**)

Figure 7. Short clips from the 4D simulation footage: (**a**) Reinforcement delivery and unloading; (**b**) Reinforcement installation (offices—foundations slab); (**c**) Concrete works (offices—foundations slab); (**d**) Columns assembly (offices—ground floor); (**e**) Concrete works (offices—ground floor slab); (**f**) Roof bracing assembly (offices—roof); (**g**) Roof panels assembly (warehouse); (**h**) Facade panels assembly (production plant); (**i**) Formwork removal.

The final building on the construction site after site demobilization works is shown in Figure 8.

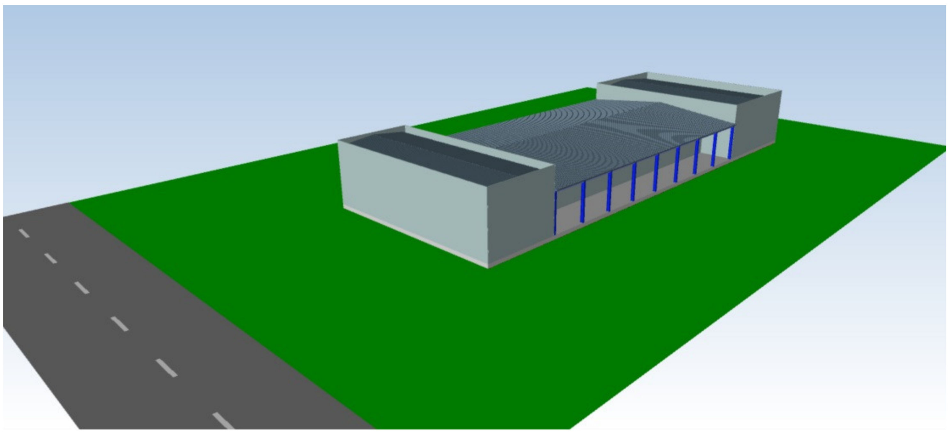


Figure 8. Production hall on the site after the site demobilization works.

4. Discussion

Results show that site logistics in the BIM environment during the mobilization phase should be planned through the three steps. In the first step, temporary facilities and storage spaces should be placed on the construction site according to the predefined standards. This is an important step to set the preconditions for dynamic analyses of machinery movement and material handling. In doing so, automated solutions, which include rules for temporary facility positioning and storage calculation, could be used [21]. Second step consists of two substeps, which are the schedule definition for site logistics planning and resources assignment. Finally, in the third step (dynamic site layout creation in the BIM environment), additional properties and settings should be implemented to enable the construction of elements, machinery movements, and material handling on the construction site. For elements and material handling simulation, appearance profiles should be defined, which includes the definition of start, active, and end appearance profiles but also the growth simulation profile definition. Additionally, for the trajectories of movement definition, 3D paths should be defined and specific activities and resources should be assigned to them.

As there are currently no standards covering site logistics analyses in the BIM environment (which would then define the level of detail of the construction schedule to enable SLP), the activities in a detailed schedule for the construction phase should be further divided into work operations. Furthermore, results show that 4D BIM software for site planning is adequate for SLP in the mobilization phase, but also that the BIM model should be developed in LOD 400, while resources should be presented by BIM objects with real dimensions (Table 5).

Table 5. Requirements for dynamic site layout development in the BIM environment during the mobilization project phase.

Requirements	Description
BIM tool	4D BIM software for site planning
Resources	Temporary facilities, storage spaces—BIM objects Materials—BIM model LOD 400; BIM objects (in material storage) Machinery—BIM objects with assigned trajectories of movement
BIM model (LOD—3D BIM model)	LOD 400
BIM model (LOD—resources)	BIM objects with real dimensions (embedded from equipment libraries or other software packages)
BIM model (LOD—schedule)	Each activity shall represent one work operation

The presented division of activities enables dynamic SLP in the BIM environment, especially assigning machinery and activities to the 3D paths and simulation of material handling (Table S2). According to the results, generalized activities for dynamic site layout creation were finally extracted and presented in Table 6.

First is *material delivery*, which should be further divided into five activities: truck arrival (material is on truck and truck with material moves according to the assigned 3D path); forklift positioning for unloading (forklift moves according to the assigned 3D path); truck stop (material disappears from the truck due to the unloading process); forklift repositioning (forklift with material moves according to the assigned 3D path); truck departure (truck moves according to the assigned 3D path) (Table 6). Mentioned activities should also be the same for *material removal*, where the material is not unloaded but loaded and removed from the construction site. Cargo simulation is important for indispensable dynamic collision detection, resource management, workspace management, and workspace conflict identification. All defined activities can be repeated several times depending on the number of rounds during material delivery.

Third is *formwork and reinforcement installation*, which should be divided into two activities. If formwork installation is executed without machinery, during the execution of this activity material should appear at the place of the future element and should disappear from the stock (Table 6). Moreover, if reinforcement is transported by using a mobile crane, crane boom rotation should be simulated (Table 6).

Fourth is *concrete works*, which should be dived into further activities: truck concrete pump arrival (truck concrete pump moves according to the assigned 3D path); truck mixer arrival (truck mixer moves according to the assigned 3D path); truck mixer stop (during concrete works); truck concrete pump stop (during concrete works); truck concrete pump departure (truck concrete pump moves according to the assigned 3D path); truck mixer departure (truck mixer moves according to the assigned 3D path) (Table 6). In the case where concrete work is executed only by truck mixer or similar machinery, the activities related to the truck concrete pump should be deleted or appropriate activities with corresponding machinery should be added.

Table 6. Generalized activities for the site logistics planning.

WBS Level	Activities	Materials	Machinery
1. Material Delivery	1.1. Truck arrival	Material on the truck	Truck
	1.2. Forklift positioning for unloading		Forklift
	1.3. Truck stop (during unloading)	Material disappears from the truck	Truck
	1.4. Forklift repositioning (during unloading)	Material on the forklift Material appears in the stock	Forklift
	1.5. Truck departure		Truck
2. Formwork and Reinforcement Installation	2.1. Formwork installation	Material appears on the place of the future element Material disappears from the stock	
	2.2. Reinforcement installation	Material appears on the place of the future element Material disappears from the stock	Mobile crane
3. Concrete Works	3.1. Truck concrete pump arrival		Truck concrete pump
	3.2. Truck mixer arrival		Truck mixer
	3.3. Truck mixer and truck concrete pump stop (concrete works)	Material appears at the place of the future element	Truck mixer Truck concrete pump
	3.4. Truck concrete pump departure		Truck concrete pump
	3.5. Truck mixer departure		Truck mixer
4. Formwork Dismantling	4.1. Formwork dismantling	Material appears in the stock	
5. Assembly (with Machinery)	5.1. Mobile crane positioning		Mobile crane
	5.2. Forklift repositioning for assembly		Forklift
	5.3. Mobile crane stop (during assembly)	Material appears at the place of the future element	Mobile crane
	5.4. Forklift repositioning (during assembly)	Material on the forklift Material disappears from the stock	Forklift
6. Assembly (without Machinery)	6.1. Element assembly	Material appears on the place of the future element Material disappears from the stock	
7. Assembly (just-in-time Material Delivery)	7.1. Truck arrival	Material on the truck	Truck
	7.2. Truck stop (during unloading)	Material disappears from the truck	Truck
	7.3. Truck departure		Truck
	7.4. Element assembly	Material appears on the place of the future element	
8. Material Removal	8.1. Truck arrival	Material in the stock	Truck
	8.2. Forklift positioning for loading		Forklift
	8.3. Truck stop (during loading)	Material appears on the truck	Truck
	8.4. Forklift repositioning (during loading)	Material on the forklift Material quantity disappears from the stock	Forklift
	8.5. Truck departure	Material on the truck	Truck

Assembly (with machinery) is the fifth type, which should be divided as follows: mobile crane positioning (mobile crane moves according to the assigned 3D path); forklift repositioning for assembly (forklift moves according to the assigned 3D path); mobile crane stop (during assembly material appears on the place of the future element); forklift repositioning (during assembly material is on the forklift and forklift changes position from the stock to the mobile crane according to the to the assigned 3D path, material disappears from the stock) (Table 6). All these activities (or some of them) can be repeated several times, depending on the number of tacts during element assembly. Furthermore, crane boom rotation can be simulated during the element assembly.

Finally, *formwork dismantling* and *assembly (without machinery)* are examples where activities in the detailed schedule for the construction phase and detailed schedule for site planning should be the same because of the absence of the machinery. Thus, only material handling should be simulated. During the execution of the formwork, dismantling material should appear in the stock, while during execution of element assembly, material should appear at the place of the future element and material should disappear from the stock (Table 6). Similar to this is the *assembly (with just-in-time material delivery)*, where the main activity is element assembly, and during its execution only material should appear at the place of the future element. Because material is not displaced on the site, material is delivered just before the assembly, whereas other activities should be truck arrival (material is on truck and truck with material moves according to the assigned 3D path); truck stop (material disappears from the truck); truck departure (truck moves according to the assigned 3D path) (Table 6).

Furthermore, results also confirm the facts stated in the literature and the remaining problems:

- Dynamic site layout enables the inspection of workflow (4D) clashes [34–36], managing transport routes [22,37], the calculation of storage and accommodation capacities [38–40], supply chain visualization [41], resource management, workspace management, and workspace conflict identification [67,84];
- 3D BIM tools have insufficient functions for dynamic site layout creation [22,23], while 4D BIM software for site planning enables the creation of the dynamic layout models, which consider the actual duration for which temporary facilities and equipment are required on the construction site [21];
- Regarding data segregation in the 3D BIM model, a clear LBS and 3D model execution plan should be defined in the early stages of the project to provide clear information needed by contractors for SLP [62–64];
- LOD 400 is crucial for daily work orders visualization, while LOD 300 does not provide all necessary corresponding elements in BIM model (e.g., reinforcing bar objects) [69,73];
- In SLP processes it is necessary to distinguish the LOD of the site elements and elements of the 3D model [61];
- There is no standard definition of LOD for site elements [71] and no standardized product description within equipment libraries (ambiguous expressions and attributes, uncertain categories, etc.) [90,95,96], which requires the development of the same elements in deferent LOD to define guidelines for construction resources' LOD definition and the testing of different resources LOD in the SLP process during the development of site layout during different project phases;
- Currently, temporary structures are manually embedded to the BIM model through the equipment libraries, temporary facilities libraries, or other type of object libraries [24,68], which requires the further testing of the development processes of BIM objects (define software tools, exchange standards, problems with usage in a 4D BIM environment, process for changing the LOD of such objects, etc.).

5. Conclusions

In this paper, the set goals (Table 4) have been achieved. Firstly, the level of detail of the construction schedule for the site logistics analyses in the BIM environment during the mobilization phase has been defined. In doing so, each activity in the schedule for site logistics planning should represent one work operation to enable the simulation of machinery movement and material handling on the construction site. Therefore, activities in the detailed construction schedule should be further divided into schedule for the use of site logistics planning. Secondly, information in the 4D BIM model which enables dynamic site layout creation has been defined. In doing so, results show that data in the 3D BIM model should be properly segregated into different levels (project, buildings, floors, construction elements) to enable the assignment of 3D objects with an appropriate activity in the schedule. Furthermore, when creating a dynamic site layout in the BIM environment, additional properties and settings should be implemented to enable element construction, machinery movements, and material handling on the construction site.

Accordingly, these results (Table 5) serve as the initial step for the further standardization of the BIM model for SLP in the BIM environment. Input data for site logistic planning in the BIM environment are well hierarchically structured in the 3D BIM model, WBS, detailed schedule for construction phase, and resources constraints definition as well as the defined necessary onsite temporary facilities. Furthermore, SLP processes in a BIM environment include three steps: temporary facilities and storage spaces placement; schedule definition for site logistics planning and resources assignment; and 4D BIM modelling and dynamic site layout extraction. Following these steps, contractors can create dynamic site layout according to the BIM principles. Furthermore, the developed structure of BIM data provides inputs for Exchange Information Requirements (EIR) for the construction execution phase, which includes requirements for site planning and site layout creation.

Limitations of the research are the following: the activity duration in detailed schedule for site planning was estimated only to enable machinery movement and material handling simulations; limited resources were simulated—workers, scaffolding, equipment, and workspace were not included in analyses; the number of rounds of machines were not simulated, which could possibly affect other activities connected to the SLP. Since the research was conducted in very limited conditions, results should be tested in different environments (e.g., different type of project, different size of project, other BIM authoring tools, other 4D BIM tools, different type of resources, health and safety analyses, more complex internal traffic routes). For example, if the case study tested was bridge or road construction project, the data segregation in the 3D BIM model, WBS levels, and detailed schedule organization would be different. Additionally, in future research, the possibility of standardizing the calculation of activity duration should be examined. Mentioned activities would than enable the definition of factors and guidelines for standardizing SLP processes within the BIM environment.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su14116701/s1, Table S1: WBS for construction phase and detailed schedule for the construction phase; Table S2: Detailed schedule for site logistics planning in the BIM environment (mobilization phase).

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