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BIM level of detail for construction site design

Marco L. Trani[a], Manuele Cassano[a]*, Davide Todaro[a], Benedetta Bossi[a]

[a]*A.B.C. Department, Politecnico di Milano, Via Ponzio 31, 20133 Milano, Italy*

Abstract

Construction site design needs to be developed in different phases of a construction process. An early report of the research highlighted, in fact, a precise structure of contents both for pre-design (until tender) and for execution-phase design based on a systematic approach. The research is now going on applying Building Information Modeling technique to that structure, assuming the strategic role of site design in the whole design process in order to meet the safety goal as well as the time-cost requirements of a project. The actual stage issue is to identify and develop a standard design BIM-based method in order to create a proper "Construction site information model" (CoSIM). The final aim is therefore to help site designers to reach primarily the required health and safety employees' standards. CoSIM method needs to be supported by an inventory of BIM elements, made on 3d-models, supplied with their ergo-technique information. That inventory has been therefore developed upon a precise classification made on different elements type (equipment, facilities, plants) according to their function on construction site. The research methodology for translating ergo-technique contents in a BIM has followed therefore these steps: (i) definition of elements to be contained in a CoSIM; (ii) definition of graphical level of detail of the model and its elements; (iii) definition of ergo-technique information level of development; (iv) translation of the model into proper deliverables.
Some results of the first three steps of the research here presented show the development of construction site design from the pre-design to the execution-design phase in a case study through which it has been possible to asses and refine some guidelines for the creation of the postulated Construction Site Information Model.

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Keywords: Information Modelling; Construction Site; Site design; Health and Safety

* Corresponding author. Tel.: +39-02-23995764; fax: +0-000-000-0000 .
E-mail address: manuele.cassano@polimi.it

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1. Introduction

Construction site design – or ergo-technique design – is becoming more and more important among design disciplines. In fact, it is able to improve design performances driving choices in order to respect times, costs and safety. From many years, the task group has worked on this direction trying to regulate ergo-technique discipline in order to reach the goal of assuring project able to satisfy the cited needs. The first step of this research was the disciplinary reorganization assumed [5] that drove the sequent, included the ongoing one about BIM application for construction site. In particular is significant to underline the importance of the subdivision of ergo-technique design discipline in *construction site pre-design* activity and *construction site execution-design* activity. The first one is carried out by a designer appointed by the client during contract design phase (until tender). Contractor and subcontractors, after the tender, produce the second one starting from the contents of the first. Table 1 resumes the principal themes of each of two stages which are strictly related since execution-design must follow and develop pre-design phase.

Table 1. Structure of the ergo-technique design [5].

CONSTRUCTION SITE PRE-DESIGN
Project Contextualization
Functional-spatial design (productive site)
Technological-plant design (productive site)
Process analysis (construction phase)
Process planning (construction phase)
Organizational modeling
Health & Safety Coordination planning
CONSTRUCTION SITE EXECUTION DESIGN
Site organization
Site operational management
Production operational design
Operational safety planning

In particular construction site pre-design should be developed -and it is compulsory for public works in Italy in three different steps following the steps of other design disciplines [5]:

- *Preliminary ergo-technique level*: “design for Client” that identifies qualitative and functional aspects of the works to be performed in order to evaluate the general characteristics of construction site and its context that may be of influence on the general morphology of the building.

- *Definitive ergo-technique level*: “design for Authority” that contains all the elements for granting permissions and required approvals. It develops in detail the site and workplaces layouts and provides a site economic framework.

- *Executive ergo-technique level*, “design for Construction Company” that determines in detail the works to realize by the company, updating the definitive level and defining site organizational issues.

This ergo-technique design breakdown has been followed for the development of a series of contents for a Construction Site Information Model (CoSIM) [6] both for pre-design and execution-design. The aim is to improve construction site issues of BIM discipline, assuring also integration with others. A precise structure of contents has been created, with a specific level of detail (both graphical and informative) for each phase, in order to make a faster and better ergo-technique design of the execution phase of a project.

2. Literature review

Many studies in recent years are trying to implement the use of BIM in order to gain benefits in different aspects of the construction process including the management of the construction site and the use of models on-site. From a site design point of view , two main aspect are underlined by international researches: 4D scheduling, Safety or both together. 4D scheduling research started several years ago with 3D CAD systems implemented with time in order to visualize the works progress. With the development of BIM the research on 4D scheduling obviously moved on this system since the chance to insert "time information", automating [1] the link process between 3D objects and schedule. Most of the intervention underline the utility of these issues in visualization of construction phases in order to have a better view of works and, first of all, of safety aspects (e.g. visualize spatial criticalities during time, design of construction site layout in different phases, study temporary strength of structure during construction phase, etc.) [7]. In fact, safety is the other main issues of construction site and BIM researches. Lots of researches aim to a better visualization in order to point out safety criticalities for workers. Some contributions, therefore, add some aspect for the production of safety planning [3] also taking into account information contained in the model (for example spaces calculation or guardrail quantification) [2]. The way traced is that of automatic checking of some safety rules (some tests are made for the automatic control of falling risk and need of falling protection guardrail) [8]. From the point of view of BIM & Safety is important to mention "BIM for construction" guidelines of CoBIM Finland Standard and NYC Building Department document for "Building Information Modeling Site Safety Submission" Guidelines and Standard. These and other contribution has been taken into account in outlining a precise structure of a Construction Site Information Model and suited to the contents defined for both phases of ergo-technique design. Therefore detail definition for CoSIM and its elements takes into account the diffused measures such as LOD [11]

3. CoSIM Pre-Design

3.1. Project contextualization

This area aim to study and solve possible criticalities of the context against construction site. Since those criticalities are existing physical/environmental elements, BIM level of detail has to be developed with particular attention to the exact dimensions of elements. In addition some elements (in particular existing outdoor or indoor plants) must be promptly visible in the model by using specific colors. Each element must be also described by information regarding the specific criticalities that affect construction site such as possible damages for workers or additional work required by site organization. Since the criticalities drive all site design, this area must be undertaken in the pre-design phase with an accurate detail level that remains the same in the subsequent phases. Therefore, the context is well known yet in the preliminary phase and can be analyzed at once.

3.2. Functional-Spatial and Technological-Plant design

These areas are strictly related since they take in consideration each element of a construction site system (such as equipment, sheds, aerial handling machines, fences, scaffolds, etc.) with its functional, technical and spatial features. In the preliminary level, since the scarce detail definition of the works, these characteristics can be outlined at first as volumes that represents the elements with the aim of general layout of the site system. Starting from definitive level, in order to describe better these areas, a specific standardized inventory of BIM elements has been created with defined graphical and informative level of detail. The inventory follow a precise classification of different element's types (i.e. technological, productive, functional-spatial systems). The definition of detail levels in ergo-technique definitive pre-design is based on performance specifications needed in this phase. For these reason CoSIM elements are characterized by some information giving minimum or maximum performance to be satisfied then in execution-design phase. Furthermore, the chosen graphical level of detail is simple in order to show the general type of the element without specifying the real element in commerce that will be chosen by the firm during execution phase. Such a simplicity in modeling result very suitable for this phase of design in which CoSIM has to follow and, at the same time, drive multiple/continuous changes of other design disciplines.

3.3. Process Analysis and Process Planning

Process analysis describes the phases of the production process necessary to the realization of the works, underlining the necessary human, material, technological and temporal resources. Process planning uses these resources to plan the works phases in detail. The output is the work plan and the definition of construction site phases (a period where the site doesn't change layout). CoSIM adopts, from definitive level, 4D methods to visualize construction advances and manage single phases by designing site and establishing the works chain. About process analysis, pre-design CoSIM, yet in definitive level, goes to a high level of detail showing possible solutions even for individual work places, if required, to evaluate its safety and its costs. This kind of detail is also useful for the construction company for identifying in detail work to be performed and carry on its own design in function of its productivity issues.

3.4. Organizational Modeling and Health and Safety Coordination Planning

These areas take into account organizational and management factors and bring to the production of proper deliverables for the whole site design. Such a design standardization helps the production of this deliverable not only with 3D images. In fact the amount of data contained in the CoSIM (that is a deliverable itself) need to be used for the organization of each site phase . An example of data mining from the model can be the calculation of safety costs (required by law in pre-design phase). In fact, CoSIM has to contain, for each phase, all the elements that represent a cost for safety with their quantities and prices. This area requires information to be developed in the model in the different levels adding from preliminary to executive level more information detail to fit, step by step, the needs of Client, Authority and Construction Company. Table 2 shows the contents of CoSIM pre-design with the gradual development on its three different levels. The table do not show Organizational Modeling and H&SCoordination Planning since information useful for these areas are developed in other areas of site pre-design. It's important to underline that all areas are related and need to be carried on in parallel during the three phases. In addition the division in the three phases has not to be considered as a strict rule for three different deliverable. In fact CoSIM pre-design has to be considered as a complete process for the tender and some detail can be studied before or after in function of general design developments and of the need of the single project and its stakeholders.

Table 2. CoSIM pre-design levels.

***Content*/phase**	**Preliminary CoSIM level**	**Definitive CoSIM level**	**Executive CoSIM level**
Project contextualization	Graphical detail yet completely developed with identification color and right dimensions and position Information detail yet completely developed with possible damages for workers and external anthropic activities	As in preliminary level with further information development, if thereafter detected or required.	As in preliminary level with further information development, if thereafter detected or required.
Functional-spatial design	Graphical detail represented by areas and volumes defining in general site spaces.	Construction site layout and working places design in its different phases with dimensionally flexible elements taken from a pre-made inventory	Update of the site and working-places layout if required by executive details of the works.
Technological – Plant design	Graphical detail represented by simple objects showing the principal needs of the construction site	Representation of the construction site layout and working places in its different phases with elements taken from a pre-made inventory with a defined graphical and informative level of development	Update of the working-places layout if required by executive details of the works.
Process analysis	Analysis of the general site phases for gaining first site data and general site times and costs	Detailed analysis of site phases and planning of the works to be carried on to gain definitive site data and define site time and costs	Update of the analysis of work phases to refine times and costs and to define site data to be transferred to the construction company

Process planning	Definition of some general site phases according to the project development	Definition of site phases according to the works to be carried on	Refine of work plan to definitively underline potential interferences

4. CoSIM Execution-Design

4.1. Site organization and site operational management

Performance specifications given in the functional-spatial and technological-plant pre-design have to be satisfied by Contractors with technical specifications. Therefore, CoSIM site organization consists of the development of CoSIM pre-design using contractors' own technical resources. Therefore, a different inventory of elements has been created for this phase made by 3D models of real equipment currently used on construction site. Contractors have to use this inventory according to their proper organization satisfying pre-design specifications. Therefore, both graphical and informative issues of each element of the inventory are more detailed.

4.2. Production operational design and operational safety planning

These areas develop procedures and operating instructions in accordance with the process analysis of pre-design phase. For this reason each construction firms, starting from pre-design CoSIM, analyses its own individual portion of the works and goes in detail designing a specific procedure for that work. In this way construction firm is able to study in deep single working places in a detailed working sequence and to evaluate real feasibility of single operation without affecting safety of workers and anthropic external activities. Therefore, such a detailed study is very useful for workers, who can visualize their tasks and each position they have to take. Their training could be in fact achieved using some sheets of CoSIM 3D views or IT equipment (i.e. tablets, smartphones) [4].

That way, execution CoSIM becomes a part of the Operational Safety Plan of each firm that have to be checked by the safety coordinator at project execution stage.

5. Case study overview

The contents of the presented structure have been developed by applying CoSIM design to real case studies. In general, ABC Dept. task group has been part of design teams -with the role of construction site designer- during design phase. Furthermore, during execution phase it had the opportunity to assess the usefulness of the design method applied. The case study here presented concerns the demolition of a building and some interventions on the neighbouring structure. In particular the trucks entrance showed in Figure 1 is the part subjected to structural reinforcement?, while the building on its left has to be demolished. Since the preliminary CoSIM pre-design, due to the lack of spaces, construction site has been designed on a portion of the street in front of the buildings subject to intervention in order to guarantee spaces for general site logistics. This part of construction site consists in two main areas joined by a metal carpentry portal essential to allow the use of the trucks entrance and of the emergency exit of the neighboring building.

These areas are mainly used for procurement and demolished material handling (area on the left in front of the building to be demolished) as well as general site logistics and tower crane placement (area on the right).

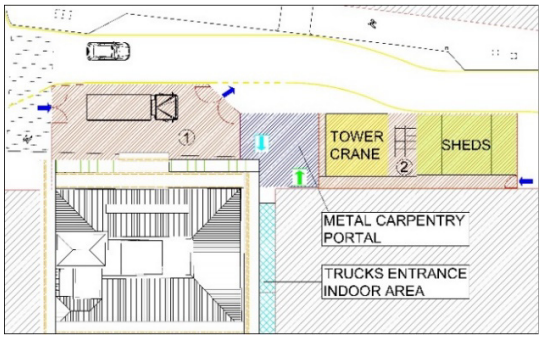

Fig. 1. Pre-Design 2D Site Layout.

The CoSIM pre-design was produced during the whole design phase -since preliminary level- and developed the general site layout. It took into consideration elements of project contextualization, functional-spatial and technological-plant design. In addition, process analysis was developed studying structural reinfocements sequence of the trucks entrance.

The need of modelling context came from the area of intervention that is in the center of the city of Milan. In particular, all the surrounding buildings and the streetlights were modelled in detail since preliminary level to show clearly possible interferences with construction site. In this phase buildings have the graphical level of detail of simple solids but lighting plants are yet modelled as red cables and floor grids are showed. The aim, in fact, is to give yet evidence of the site criticalities due to these pre-existent elements. Regarding information level of development lighting plants were implemented with some parameters that give an overview of possible damage for workers due interference and the parameter “remove” as a likely solution to avoid these damages.

Functional-spatial and technological-plant design regarded all the elements inserted in CoSIM to produce the site layout. In early preliminary phase, as showed in figure 2, some general volumes and areas has been developed in order to have a first idea about the needs of the demolition site according to the context constraints (i.e. the busy street, the existing aerial and underground plants, vehicle and people entrances, etc.)

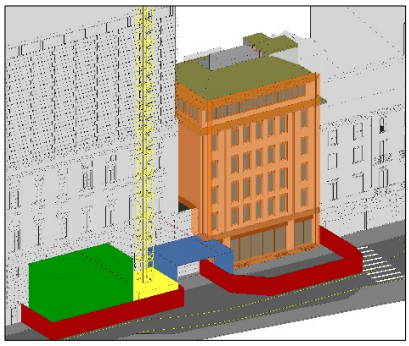

Figure 2: General site spaced outlined in preliminary phase

These volumes has been detailed in definitive pre-design level by adding the elements taken from the inventory of pre-made site BIM objects. The following table 3 presents the study of some of these elements and in particular: fences; scaffolding; sheds and tower crane; the same table explains criteria of graphical detail and shows information inserted for each of these elements in the design phase. In addition, figure 3a shows a view of the produced definitive CoSIM pre-design for a single phase.

Table 3. Elements of CoSIM pre-design.

Element	Graphical level of detail	Related parameters			
Fences	Show site boundary, typology, dimensions, strength and permeability requirements (cost to be evaluated).	• Length • Permeability	= 70 m = Blind	• Min. height • Strength: traffic damage resistant	= 2,50 m
Scaffolding	Show its presence where needed in each phase and its size (cost to be evaluated).	• Total Area	= 600 m^2		
Sheds	Show their number, location, minimum/ maximum size.	• Maximum Length	= 5 m	• Min. Internal height	= 2,70 m
Tower Crane	Show min./max. dimensions related to context constraints.	• Minimum height • Min Load	= 60 m = 3 tons	• Min. Boom Length • Max. Boom Length	= 40 m = 45 m

As showed in figure 3b the level of graphical detail changes a lot from pre-design to execution CoSIM since construction firms needs obviously more detail also in information development of each elements. As a comparison with pre-design, table 4 shows the characteristics of the same elements of table 3.

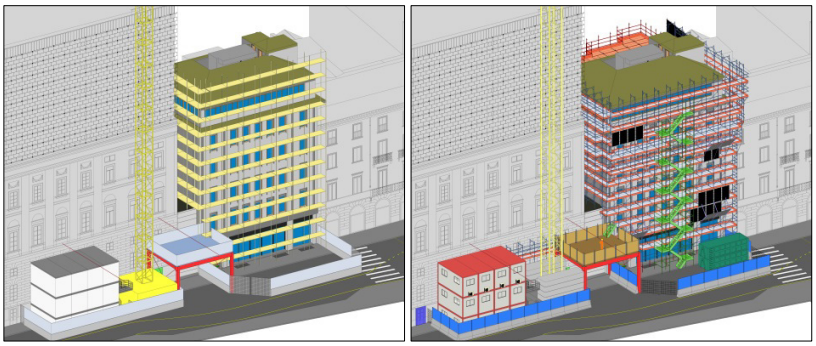

Figure 3: Site Layout, (a) Pre-Design CoSIM view, (b) Execution design CoSIM view

Table 4. Elements of CoSIM execution-design.

Element	Graphical level of detail	Related parameters			
Fences	Implement real products typology (new-jersey plus metal blind panels) with their actual characteristics.	• Total Length • Number of NJ • NJ height • NJ Material	= 67 m = 29 m = 1,00 m = Concrete	• Number of panels • Panels height • Panels Material • Panels Structure	= 87 = 1,50 m = Metal = Steel
Scaffolding	Implement real scaffolding typology (pref. frames), stair (steel flex), any other element (*e.g.* guardrails, braces, protection fans, etc.)	• Total Area • Protection fans width: 1,2 m	= 600 m^2	• Type:	Pref. Frames
Sheds	Implement real sheds typology (*e.g.* sandwich wall, passageway, MEP, etc.).	• Length • Internal height	= 6 m = 2,70 m	• Function • N° Workers	= Toilet = 10
Tower Crane	Implement real tower crane typology, operational area, etc.	• Height • Boom Length • Max. Load	= 65 m = 45 m = 4	• Counterweight dim. m • Fixing system gap	= 6,25x6,25 = 20 m

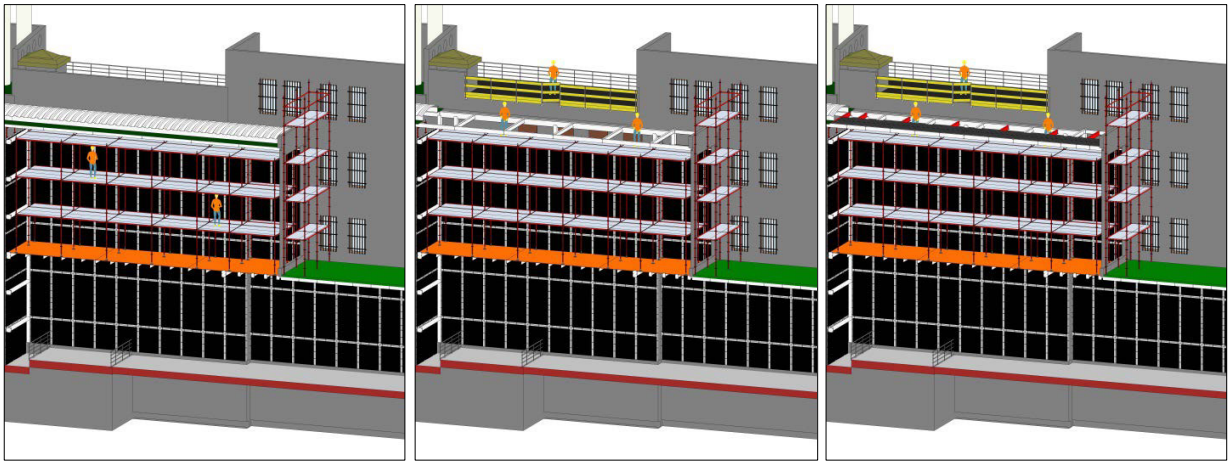

Figure 4: Operational design - Mounting sequence of the metal carpentry

The *production operational design* provided by each construction firm during the execution phase has been expanded upon the *process analysis* developed during design phase. Figures 4 shows the mounting sequence of the metal carpentry in the trucks entrance. In those views, workers can identify their role, position and safety equipment such as scaffolding and guardrails at their disposal.

6. Conclusions

The presented Construction Site Information Modelling -CoSIM- methodology carried out and tested through the design and the execution phase of the project above illustrated has pointed out some strengths, weaknesses, opportunities and threats. First of all the CoSIM approach allowed to share in a sharper way all design issues among different designers, orienting or even asking them for different technological choices considering construction site issues since the early stage of the project (e.g. steel portal dimensions, roof reinforcement, temporary structure position, etc.). The LOD-like level of detail [10] assessed for contextualization constraints, equipment, scaffolding and any other site element of interest during design phase seemed to fit Contractor information exigencies related to the subsequent production of the ergo-technique execution-design. The flexibility of the inventory created at that purpose shown its strength into the possibility to simply hand over information from a “design” (likely) to an “execution” (real) database of site elements.

The CoSIM actual weakness consists of the lack of site equipment real product BIM objects. Those used for the research project, in fact, has been developed by the task group. Therefore Contractors may consider the CoSIM approach for operational design not too developed yet.

On the contrary, the task group experimented a great convenience in using the CoSIM method from a time-cost of design point of view. Sharing and visualizing site information and situations since the early stage of the design phase with other designers allowed a strong reduction in time-waste in modifying a number of time the ergo-technique pre-design, achieving as well a better health and safety design at a lower professional cost. As the Contractor’s construction site execution design has to be approved by the safety coordinator, at the execution phase, the experimented use of a shared CoSIM abbreviate that issue which is always a threat for project managers.
The only real threat that has been noticed using a CoSIM is the model handling from the Client to the Contractor, referring to its modification permissions. Anyway this possibility is a malicious one as it is necessary the explicit willpower to do so.

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References

[1] Kim, H., Anderson, K., Lee, S., Hildreth, J. (2013), Generating construction schedules through automatic data extraction using open BIM (building information modeling) technology, *Automation in Construction*, 285-295.
[2] Qi, J., Issa, R. R. a., Olbina, S., & Hinze, J. (2013). Use of BIM in Design to Prevent Construction Worker Falls. *Journal of Computing in Civil Engineering*, 2014.28.
[3] Sulankivi, K., Kähkönen, K., Mäkelä, T., & Kiviniemi, M. (2010). 4D-BIM for Construction Safety Planning, *W099* - Special Track 18th CIB World Building Congress, Salford, UK
[4] Trani, M., Bossi, B., Cassano, M., Todaro, D. (2014). BIM and QR-code. A Synergic application cin Construction site Management, Proceedia engineering, 85, 619-624.
[5] Trani, M., Bossi, B., Minotti, M. (2013). Construction Site Design: A systematic Approach, Creative Construction Conference 2013. Budapest, Hungary, July 6-9, 2013, 787-795.
[6] Trani, M., Cassano, M., Minotti, M. and Todaro, D., (2014), Construction site BIM requirements In: Procs 30th Annual ARCOM Conference, 1-3 September 2014, Portsmouth, UK, Association of Researchers in Construction Management, 663-672.
[7] Vimonsatit, V., & Lim, M. (2014). Use of BIM tools for site layout planning, ASEA-SEC-2 Sustainable Solutions in Structural Engineering and Construction, Bankok, Thailand, November 3-7, 2014, 755–760.
[8] Zhang, S., Teizer, J., Lee, J., Eastman, C., Venugopal, M. (2013). Building Information Modeling (BIM) and Safety: Automatic Safety Checking of Construction Models and Schedules. *Automation in Construction*, pp. 183-195.
[9] COBIM Common BIM Requirements 2012, Series 13: Use of models in construction, Finland
[10] NYC Department of Buildings 2013, Building Information Modeling Site Safety Submis-sion Guidelines and Sandards.
[11] AIA 2013, Building Information Modeling and Digital Data Exhibit