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ENGINEERING OF ARCHITECTURE

BACK TO 4.0:

RETHINKING THE DIGITAL CONSTRUCTION INDUSTRY

A cura di

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"Adding construction workspaces modeling and planning to a 4D BIM-based Simulation Model"

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Topic: Models for design and construction, Project construction and integrated system Management

Abstract

As building information modeling (BIM) systems continue to be widely adopted, there is an increasing demand for an active construction management systems with more advanced and effective decision-making capabilities. Moreover, BIM-based Four-dimensional (4D) model, which links three-dimensional geometrical models with construction schedule data, emphasizes the construction components' progress concluding in an object-oriented simulation. Have been demonstrated that this kind of approach is not consistent for improving construction safety and productivity. The presented work is a first step in order to develop a BIM-based design process overturning the object-oriented simulation in an activity-oriented simulation. The association of work zones, site facilities, site areas, site machineries and material procurement to each building components and sizing each of them from a BIM-based quantity take-off are identified as the key components for a successful site planning. Nevertheless the existence, the dimension and the location of site areas can be varied across the construction stages. Without proper planning, unnecessary facility relocations may be required in each construction stages, resulting in a higher construction cost and longer construction time due to need to dismantle and set up site facilities. In this perspective site layout plans should be optimized using a multi-stage model within a BIM Environment to avoid unnecessary changes for improving site efficiency. This is carried out including a modeling workflow in order to pair all the activities which requires the same site areas, site facilities and so forth. A case study using the proposed method for the case of a Renovation in complex site condition is given.

1. Introduction

Space is a limited resource on a construction site. Labor, equipment, temporary facilities, and material deployment areas have different space requirements and they compete with each other for space usage throughout the entire life of a project. (Xing Su and Cai 2014).

Furthermore the workspaces requirement of a construction activity change over time in terms of geometry and location, leading to a sequential series of workspaces composing the life-cycle workspace evolution associated with the construction activity. Guo proved that deficiencies in workspace planning might cause congested jobsites, loss of productivity, space conflicts, and schedule interferences or delays (Guo, 2002). Hence, planning, control and manage this dynamic interaction between activities and their workspaces becomes essential in perspective to reach a safer and more productive construction site. Moreover incorporating workspace considerations from the spatial and temporal perspectives in the project planning and control process has become a key prerequisite to project success in terms of guarantee of the project constructability requirements.

Several studies, with different perspective, have been carried out in order to describe the different processes involved in workspace management. Akinci et al. firstly developed space templates linked to construction method to enable users to define the space requirements of different construction methods (Akinci et al., 2002). Dawood and Mallasi applied entity-based 4D CAD technology for detecting workspace congestion to help identify potential safety hazards on-site using critical space-time analysis (CSA) in 4D visualization (Dawood and Mallasi 2006). An integrated approach in which workspaces are generated using the bounding volume of each individual object and then linked with schedule activities in a 3D CAD Environment was proposed (Moon et al. 2014). Continuing, Su and Cai presented a lifecycle approach to the modeling and planning of construction workspaces taking into account the evolution pattern of activities' space requirements (Su and Cai 2014). A 2-Dimensional visualization of safety workspace with a classification based on manpower, machineries, plants and scaffolding strictly linked with the breakdown of the construction details was proposed (Capone et al., 2014).

Whereas the spaces variability over time has been considered in the four-dimensional (4D) modeling [i.e., three-dimensional (3D) space plus time], it has emerged as an effective means to integrate space and time for construction planning.

However, the existing 4D modeling technique still lacks the aspect of modeling dynamic workspaces. In the previous practice of 4D modeling, visualizing 3D objects at discrete points throughout the duration of the associated task (i.e., displaying the entire product for the whole task duration) is not representative of the construction process.

An effective 4D Building Information Modelling (BIM)-based workspace modeling method is required to flexibly, conveniently, and accurately reflect the real workspace usage.

This paper presents a 4D BIM-based system for planning construction activities and developing a constructability analysis, which aims to satisfy the following conditions:

- Design of a workflow which aims to obtain a BIM-based 4D Model which comes in handy to verify constructability requirements of a BIM-Model.
- Consideration of workspace structure which means which kind of workspace and how they are organized to accurately represent a construction activity.
- Consideration of the geometric modeling aspects which include how to determine the number and the dimensions of the workspaces.
- Take into consideration the real dimensions and shapes of the site facilities.
- Sensitivity analysis: this means the quantification of a given construction layout with different parameters.
- Safety consideration (e.g., safety zones around construction area and facilities etc.).
- The possibility to use the developed system also for special building construction sites (e.g., restrictive spatial conditions like in the building renovations).
- Evaluation of the logistic behavior of the site, site equipment and their interactions with the environment during the execution as well as checking the smooth movement of material flow, taking into account the possible collisions.

2. Methodology

Aforementioned objectives were achieved starting from a theoretical-methodological approach that enables the accurate determination of dimensional parameters, that are, later on, to be addressed to the model objects. Starting with BIM-Model, Figure 3 shows the proposed workflow, which is described step-by-step in the follow. The following illustrations shall relate to the case study building, which will be better introduced in the next paragraph.

Step 1. (*Activity Scheduling*) Consists in the breakdown of the intervention, for which a 4D BIM-based model is desired, in different activities following the logics as for Work Breakdown Structure (WBS). Following rules of the Location Breakdown Management System (LBMS) (Russel 2010) the building is divided by floor and each floor in sub-space clusters. Hence, each singled out area will be coded in order to be uniquely identifiable ($ID_{BuildingSpace}$). Codes will then used to set up activities according to project scheme necessity.

Step 2. (*Activity Requirements*) This step dwells the programming of site requirements in terms of site facilities, equipment, machineries, storage, areas and labours. Such analysis will be performed for each of the single activity that was before singled out. A well-established overview table supports analysis described (Figure 1). Table lists along the y-axe analyzed activities while on the x-axe reports site facilities, equipment, machineries and storage areas. In order to maintain a tight link with the floor on issue for the specific work, last columns are dedicated to planimetry individuation of each working phase through the $ID_{BuildingSpace}$. Table is therefore easily readable via ticks that enable binary information such as "yes/no". Visualization of information in such a synthetic format is also aimed at the next step clustering of activities that are referred to the same resources in terms of site requirements.

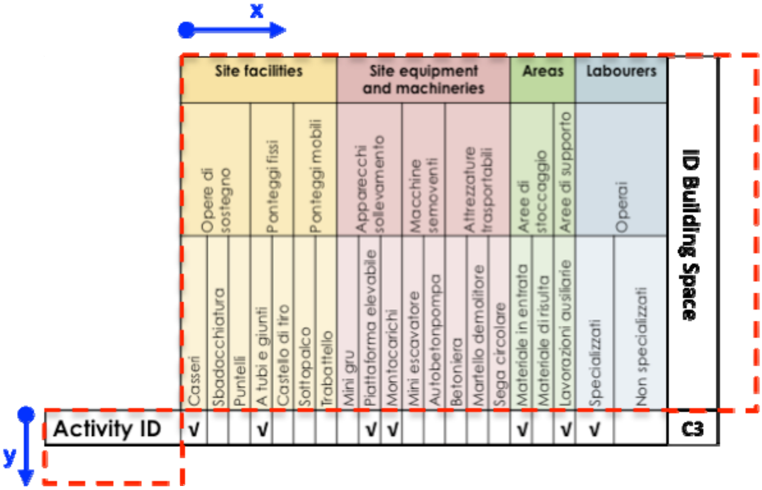

Figure 1: Synoptic table header

Step 3. (*Workspace Requirements*) Identification of site requirements in terms of check list is not enough for the simulation of workspace requirements. Hence, each requirement is singled out and analysed in terms of surface and volume: machinery chosen are referred as per their specific obstruction, workspace surfaces are split according to the specific intervention area of interest, storage areas are singled out exploiting 3D BIM Quantitative take-off.

At least, the workspace, referred to the considered activity, is defined by this research as is shown in Formula 1. Each activity has its site requirements and its requirement has its own space. For this reason the space required for each activity ($Activity_{Workspace}$) is the sum of the individual areas occupied by its site requirements.

$$\mathbf{Activity}_{\mathbf{Workspace}} = (Space_{BuildingObject} + Space_{Facilities} + Space_{Equipment} + Space_{Machineries} + Space_{LaborCrew})$$

Formula 1: Description of the Actvity Workspaces

Step 4. (*Relationship between Activities and BIM Object*) A BIM model is structured following for single objects aggregation logics which represent a single building product. Transfer from an Object-oriented to an Activity-Oriented simulation is performed conceiving each single building component, or aggregation of it, as tightly bounded to every space required by construction site. Hence, to each of the Building Component is associated an activity which is represented by a set of different spaces (cfr. Formula 1) and therefore, each Building Component will be modelled within a BIM environment as the sum of multiples BIM Objects as follows:

$$\textbf{Building Object} = \text{BIM Object}_{BuildingObject} + \text{BIM Objects}_{ActivityWorkspace}$$

Formula 2: Building Object

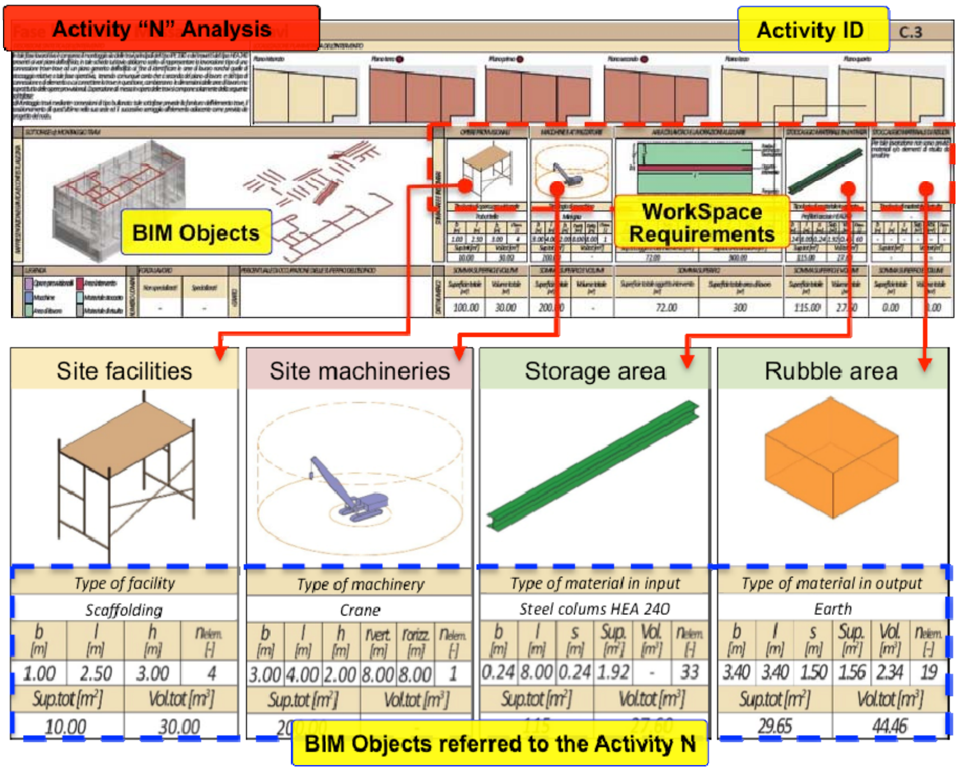

Figure 2: Dimensional chart and relationship between activities and BIM objects

Step 5. (*Improvement of the BIM objects' informative content*) Next step regards the implementation of the information derived from the 3rd step, inside the original BIM model. This consist of two phases: implementing a semantic uniformed way of mapping objects in order to facilitate the creation of the next 4D Simulation (BIM objects' informative content should include information about its site requirements and their geometric parameters, name attributes, domain specific attributes and instance-specific attributes) and modeling the workspace requirements as now BIM Objects but mapping them with the same Identification Code (ID) of the referred activity.

Step 6. (*BIM Model Plus*) From the previous step we obtain the so-called "BIM Model Plus" that represents the first model enhanced by the foregoing analysis. The latter have been translated into information content and new BIM Objects representative of the site set up simulation.

Step 7. (*Identification of the schedule-overlapping ratio*) We need now to establish the hierarchical and temporal connections between the various working steps. In order to individuate the correct sequence of works' execution, it has been realized a chart where each phase is connected to the other, in serial or in parallel, through a consequent logic that consider both natural architectural procedure and the characteristics of the building. In order to save previous information through the analysis already carried out, each step provides, in the form of tell-tale switched on or off, their site requirements.

Step 8. (*4D BIM Model*) Adding Time Dimension to each modelled object by means of a BIM Platform, the system is able to represent the construction progress by displaying the products and workspaces dynamically, benefitting from the workspace representation with both geometric and temporal attributes available. Therefore, at a specific time point, both activities workspace and finished products can be shown in the viewer (Figure 6,7). Compared to mere product progress visualization, such a workspace aware progress visualization can present richer information about which parts have been completed, which parts are under construction, and the space usage of the ongoing construction activities. The information is able to assist in construction planners to identify problems that may be overlooked when using product progress visualization.

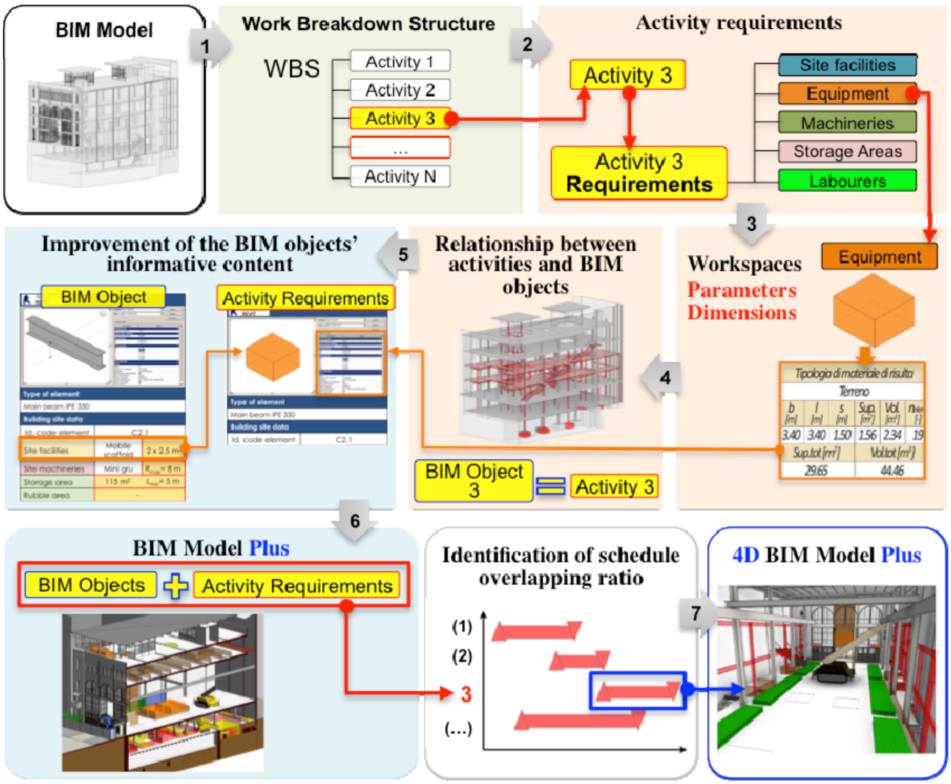

Figure 3: Principal Architecture of the presented System

3. Case study

The case study was born out of the Agreement between *Department of Civil and Environmental Engineering* (University of Florence) and the *Institut de Recherche en Constructibilité* (École des Travaux Publics of Paris), working on the ambitious urbanistic project "*Reinventer Paris*". The call aims at restoring, both architectural and structural, historical buildings of the city. Among these, there is the Sous Station Voltaire, built in 1908 in the heart of 11th Arrondissement of Paris, at n. 14 Avenue Parmentier, within an area of 600 sqm.
The main function was the transformation of the energy coming from the main electric station fueling the metro-tram line. The call foresees a variation of the use of the building to become a multiplex cinema and restaurant with the aim to create an organic construction complex in order to create a cultural aggregation center.
In order to renovate the building, both architectural and structural, we identified three macro-categories of structural interventions: part to be demolished, part to be built and finally finishing touches (Figure 4).

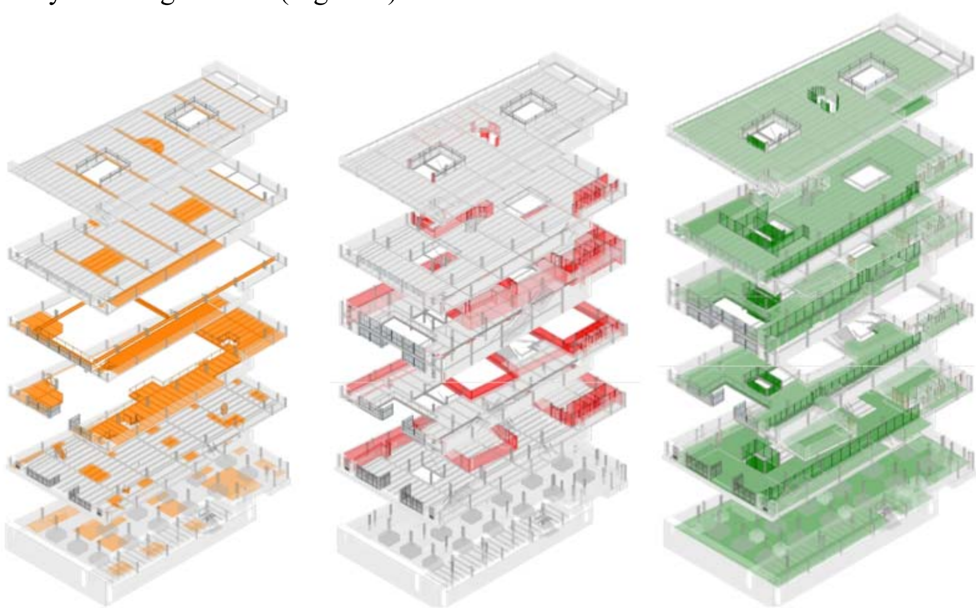

Figure 4: Three macro-categories of architectural-structural interventions: demolitions, constructions

Such a setting allowed us to implement the proposed procedure with a construction site set up study and a constructability analysis using the Autodesk BIM Platform. (Figure 5)

The 4D BIM based model, structured following the aforementioned steps, helped us to simulate the construction activities and individuate immediately the levels of criticality too. Below are the main critical identified issues:

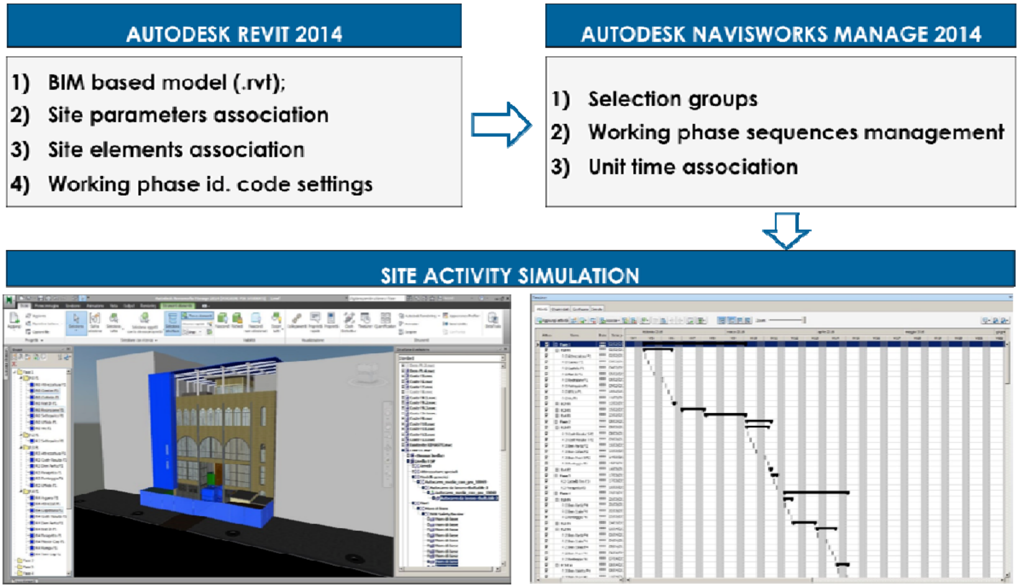

Figure 5: 4D Modeling workflow implemented in the Autodesk BIM Platform

- The **first** problem regards the assembly of the new structure that needs the drilling of the existing ground floor; by the way this fact is clashing with the effective need of the working area. We decided to change the structural drawings through the breakdown the setting of the new frame in two operative sequences: first the assembly of the perimeter structure with a small crane, that allows the production, and then the opening of the central drills to transfer the remaining part of the structure through the existing overhead travelling crane (Figure 6).

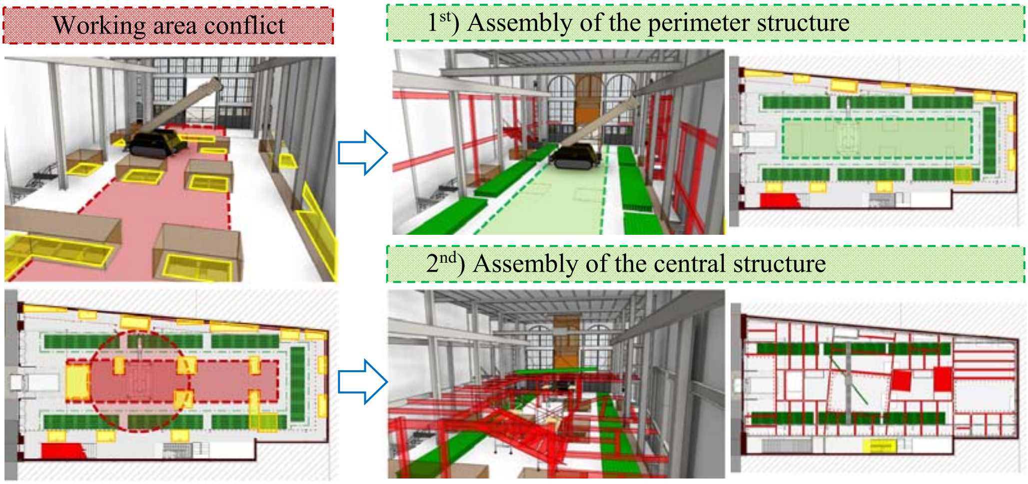

Figure 6: First critical issue - workspaces conflict

- The **second** critical issue is at the underground level where the presence of site facilities, such as supports for the ground floor, do not allow the excavations for the new foundations. We decided to change then the series of production, moving up the digging out in respect of other working steps (Figure 7).

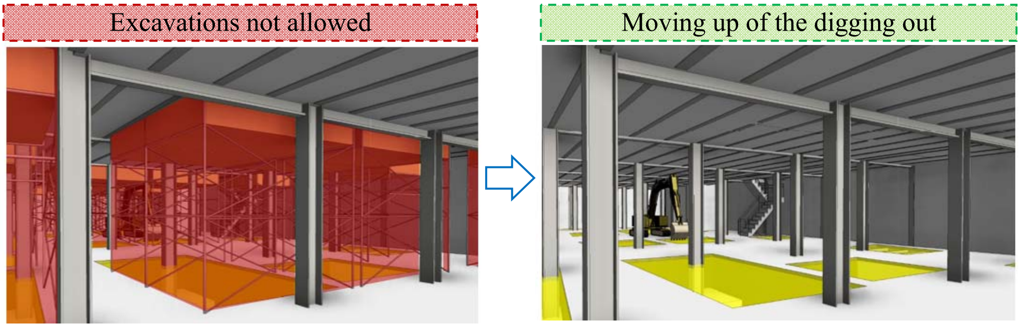

Figure 7: Second critical issue - working steps conflict

- The **third** problem is related to the raising of the beams on the 2nd floor, when the frame of the first floor has been already set up: the overhead travelling crane has not enough space to operate. We solved the problem by using columns equipped with welded beam stumps. This allowed us to reduce the length of the beams.

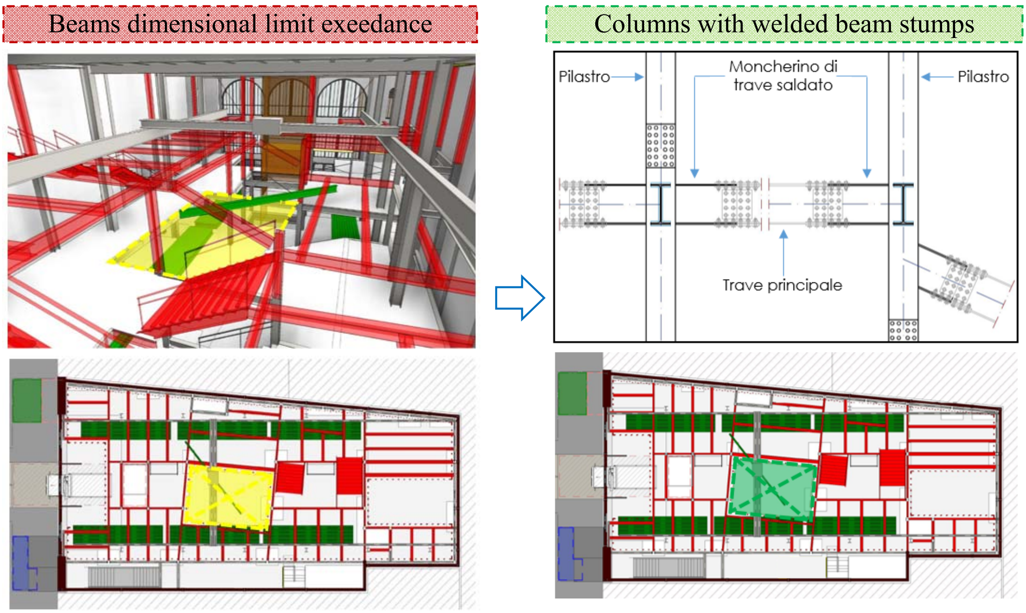

Figure 8: Third critical issue - objects dimensional limit conflict

4. Conclusion

The presented research shows how the mere use of the BIM platform is not enough to carried out a 4D Model which aims to reach a constructability assessment but structured methodology is required. Moreover, from this study has emerged the relevant connection between a 4D BIM Model and The Level Of Development (LOD), which should have been strictly connected with a 4D Model in order to obtain a simulation which is not or time-consuming, due to the time required to model, or inefficient.

7. Acknowledgment

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