Computational workspaces management: a workflow to integrate workspaces dynamic planning with 4D BIM

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Abstract

An effective realization of a building construction project -without incurring in congested site areas or decline of productivity- tightly depends on the construction activities planning process that, should consider and manage site workspaces availabilities. In this context, in the past couple of decades many research efforts have been spent in BIM which represents the process of preparation and use of a computer-generated Building Information Model (BIM) even if effective integrated methodologies and models to assist construction workspaces management are still missing in the field.

This contribution proposes an integrated model that aims to automate the creation of a building digital prototype, BIM-based, in which real site condition, in terms of workspaces allocation, are fully simulated. The outputs of a built-in algorithm to define the on-site workspaces configuration pattern based on the space syntax analysis together with a second one to automatically model workspaces geometries with minimizes input work are presented. Those algorithm are integrated in a coherent construction workspaces management workflow and tested on a simplified BIM of an industrial building, succeeding to allocate and model 611 workspaces required to construct 98 building items the BIM is composed of.

Keywords –

4D BIM; Construction workspace management; Scheduling; computational design.

1 Introduction

Whatever the type of building project under consideration, there is a need to produce a construction schedule that is considered a challenging activity for construction managers due to the number of variables they should consider especially resulting from the dynamic nature of the construction site. Considering its nature, which consist of different activities in limited area, it can be stated that '*workspace*' is the leading factor that is frequently overlooked in construction scheduling. In this sense, researches developed until now are limited in their ability to generate the workspace digital model for all activities of the building project for which workspaces are required. Most of them are focused on static 2D-based workspace models.

A practical motivation is that, since a building project is composed of a huge number activities, it is difficult for construction managers as well as researchers to automatically create at a time the workspace digital model for all the activities, due to the fact that it is a tedious work to generate the workspaces for many activities in the project using a 3D tool.

Riding this problem, the theoretical scope of this study is to automate the creation of a building digital prototype in which all the required workspaces to construct the building objects will be planned and modelled. To achieve this purpose, the use of 4D BIM and computational design will be integrated.

2 Background

2.1 Construction workspace management

Incorporating workspace considerations from the spatial and temporal perspective, in construction planning and scheduling, plays a pivotal role in proactively preventing work-space problems and decline of site productivity. According to [1], construction workspace management includes the following three branches.

1. First, *generation and allocation of workspaces*. In this regard, most of studies such as [2],[3],[4],[5] and [6] support the workspaces modelling by using manual mark-up in a 2D or 3D modelling environment. But, considering the number of required spaces for each construction activity to multiply by the huge number of activities a building project is composed of, design automation in spatial modelling is suggested but still missing in literature.

2. Second, *detection of spatial temporal conflicts*. In this context, three research branches can be identified: (a) detection of physical conflicts between the site workspaces; (b) detection of schedule conflict which means the detection of a temporal overlap between tasks that is mainly taken into account by the models which use traditional representation of the construction process (i.e., Gantt Chart and Network Diagrams); (c) site congestions identification [7] that considers the ratio between the volume of resources occupying a workspace and the volume of the workspace which is available on site for a given activity or a set of activities. Often defined as 'scheduling overlapping ratio' [8].
3. Third, *resolution of identified conflicts*. Regarding this aspect, the methodologies -proposed in literature- reveal the predominant use of mathematical models that, on one hand, are able to manage only a small part of a given building project due to the computational load entrusted to not specific calculation environment (e.g. Matlab), on the other hand require an extremely knowledgeable of the mathematical model itself which cannot be used by construction managers. For these reasons the almost always go unused.

3 Need and justification

Prevailing *activity-oriented* construction scheduling techniques -e.g., Gantt Chart, Network Diagram, Critical Path Method- are not able to consider spatial requirements of activities and for this reason the generated construction schedule is limited in capturing real site conditions. Moreover, more complex techniques -such as Line of Balance- have likewise insufficient ability for workspaces planning because they assume that only one labor crew is able to occupy each work-zone at a time and they lack of a 3-Dimensional representation and planning of spaces as well as spatial conflicts among themselves [9].

More recently, a new research trend of utilizing Building Information Modelling (BIM) and BIM-related technologies to assist construction scheduling is arising. It represents the process of preparation and use of a computer-generated Building Information Model [10], which is data-rich parametric digital representation of a building, from which relevant data, needed to support planning and scheduling of construction activities, could be extracted and used. But, in spite of its growing implementation, the use of BIM to improve construction planning has involved many efforts focusing on its technological aspects (i.e., 4D BIM-based tools) rather than on the integration with site planning models for construction workspaces management.

Therefore, an holistic workspaces planning model -BIM compliant- able to consider, simulate and analyze space availability and demand for each building object, included in a given BIM, is still missing and it could support construction managers in reasoning on the construction schedules that feature specific construction methods and concurrent execution of overlapping activities.

4 Methodology

4.1 Goal and Objectives

For the aforementioned reasons, the overall goal of this research is to define a BIM-based construction planning model that automates the creation of a building digital prototype in which real site condition, in terms of workspaces, are simulated and it should be able to guide an external user (i.e., construction manager) to define the construction sequence that guarantees the non-overlapping condition of the workspaces. In particular, this research makes the following contributions:

- it defines of a construction planning model which acts, logically and technically, on a given Building Information Model (IFC-based);
- it introduces an automated process for geometric planning and modelling of workspaces, within a BIM environment, by means of two built-in algorithm;
- it defines of a tool sets that communicate through an external data-base in which a construction manager introduces his experience in terms of workspaces requirements of construction methods;
- it guides a construction manager in defining the earliest construction sequence -visualized in 4D BIM-based simulation environment- of a given BIM to be processed.

The paper is organized as follows. First, the practical motivation for this research is introduced by using a case study together with the explanation of the working prototype. Next, an overview of the planning model and specifications about its operational framework and its computerization are given. Finally, an evaluation of this approach is provided, followed by a brief discussion of the on-going and future research.

4.2 Motivating case study and working prototype

This section describes a simplified case study that illustrates the practical motivation for this research on which the proposed workflow has been tested. An Information Model of an industrial building, structured according to the IFC-data schema, is the input of this research.

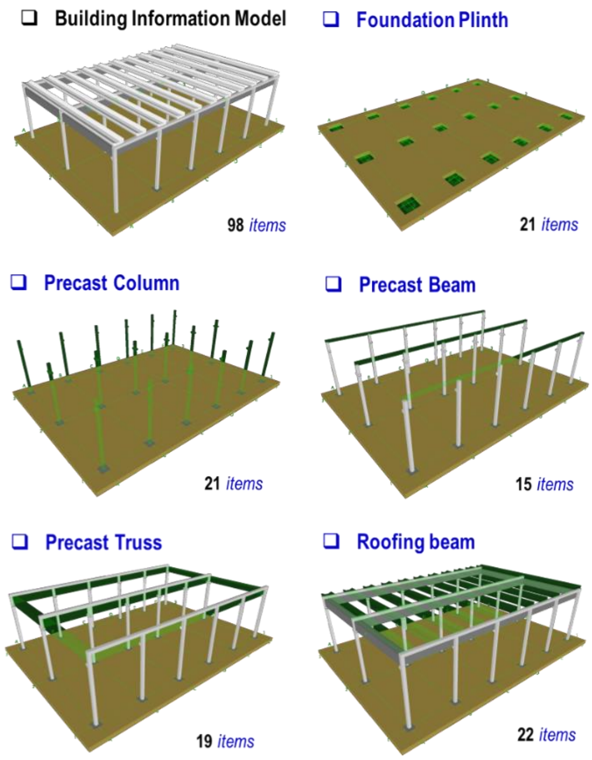

Figure 1. Building Object of the case study

Taking into account its structural subsystem but leaving aside the building finishing, the given BIM is composed of five objects types: (a) Foundation Plinth -eighteen items-; (b) *Precast Column* -eighteen items-; (c) *Precast Beam* -fifteen products-; (d) *Truss* -nineteen items- and (e) *Roofing Beam* -twenty-two elements-. Figure 1 shows the BIM filtered by type of building objects.

Trying to be a construction manager who receives the aforementioned BIM in order to define the optimal construction sequence, the proposed approach seeks to respond to the following open issues:

- Which kind of workspaces are necessary to install those five types of building objects?
- How all those workspaces should be located in site with reference to building object of which they handle the installation?
- Is it possible to automatically generate a workspaces allocation pattern using the construction manager's experience and automatically sculpt geometries of workspaces in a BIM modelling environment?
- Could it be possible to find and simulate a construction sequence by using a 4D BIM which, solving the issues mentioned above, guarantee the non-overlapping condition of workspaces?

It is clear that, to make BIMs useful for construction, all these specific information for construction site must be planned and explicit in the given information model in a way that construction managers can easily work with to better understand and plan their specific schedule which cannot be against to all those condition established in the model itself.

The architecture of the proposed solution to generate the building digital prototype in in which all the required workspaces are planned and simulated is represented in Figure 2.

The architecture shows that the planning process starts with three elements: first of all, a BIM and a structural schedule -due to the fact the latter does not depend on specific consideration but it defines the first scheduling constraints (e.g., plinths before columns, columns before beams, etc.)-; then the experience of the construction manager which is stored within an external database. It works as repository of information relevant to the workspace management process (planning and modelling) according to a predefined structure later specified.

The result is a 4D BIM Model that simulates all the required workspaces allocated in their optimal position that satisfies the conditions specified by the user (Figure 7). The computerization of such a theoretical algorithm will be described in the next paragraphs.

4.3 Problem solving approach and computerization

The proposed design process that reaches the aforementioned objects is composed by a number of operational modules in a coherent data management flow. They are graphically described in Figure 2 and briefly specified step-by-step as follows.

1. **Data extrapolation from the BIM**. Having at our disposal the BIM we are able to extract the following information: *number and types of building objects*, their *local placement on X, Y and Z-axis* (relative to the building grid axis). Those data are stored in an external database.
2. **Workspaces Database preparation**. For each object type a *Construction Method* (CM) is generated in an external database where the user adds a list of workspaces required by the CM itself in terms of *Labor Crew*, *Equipment*, *Hazard*, *Protected and Safety Spaces* according to his experience. For each space the following information are required: *Dimensions*, *Topological Interaction* with the other spaces and *Interaction Value*.
3. **Workspaces planning process**. Defined workspaces properties for each construction

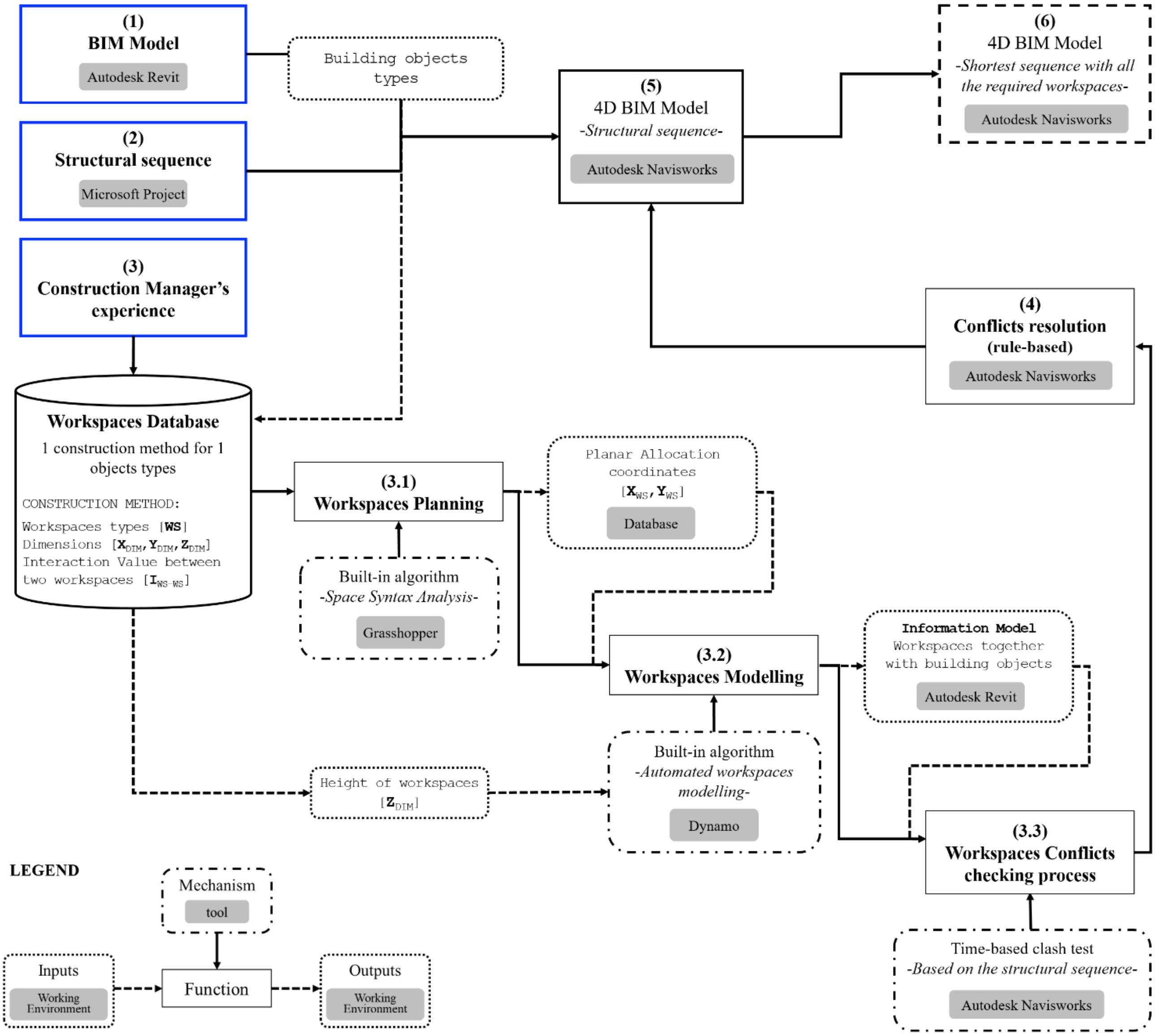

Figure 2. Data management flow to generate the building digital prototype with workspaces in Figure 7

method, it remains to find their optimal layout allocation with reference to the building objects. This is carried out by using a configurational analysis based on *Space Syntax Analysis*. The workspaces configuration pattern is generated in the form of a planar graph by using a bubble diagram which is deduced by Nourian's algorithm [11] and especially customized for our model. It read workspaces information and provides as output the workspaces allocation coordinates for each construction method (Figure 3).

4. **Workspaces modelling process**. Reading the allocation coordinates of workspaces referred to each building objects a Dynamo's script -an algorithm editing environment for computational design linked to a BIM modelling environment- automatically sculpts the geometries. By doing so each building objects is simulated with a cloud around itself that is the non-visible volume in the building needed for execution of works. As depicted in Figure 4 for each construction method and and fully in Figure 7, 611 workspaces have been automatically simulated.

5. **Workspaces conflicts checking process**. The BIM that now includes the building objects and all the needed spaces is loaded in a 4D BIM environment (*Autodesk Navisworks*) to carry out a time-bases clash test on the basis of the structural schedule. By doing so a clash report is extracted, an example in Figure 5, with the pair of conflicted workspaces.

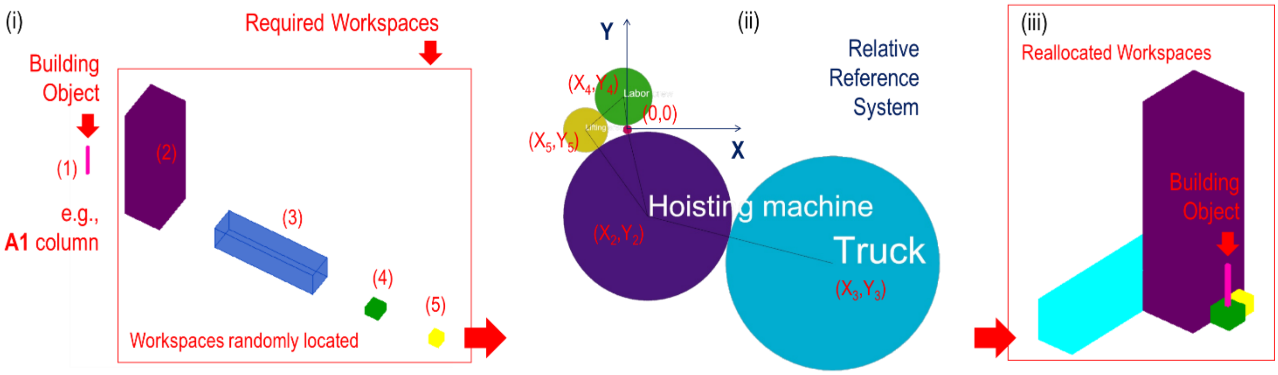

Figure 3.Planning process to find the workspaces allocation pattern around the precast column

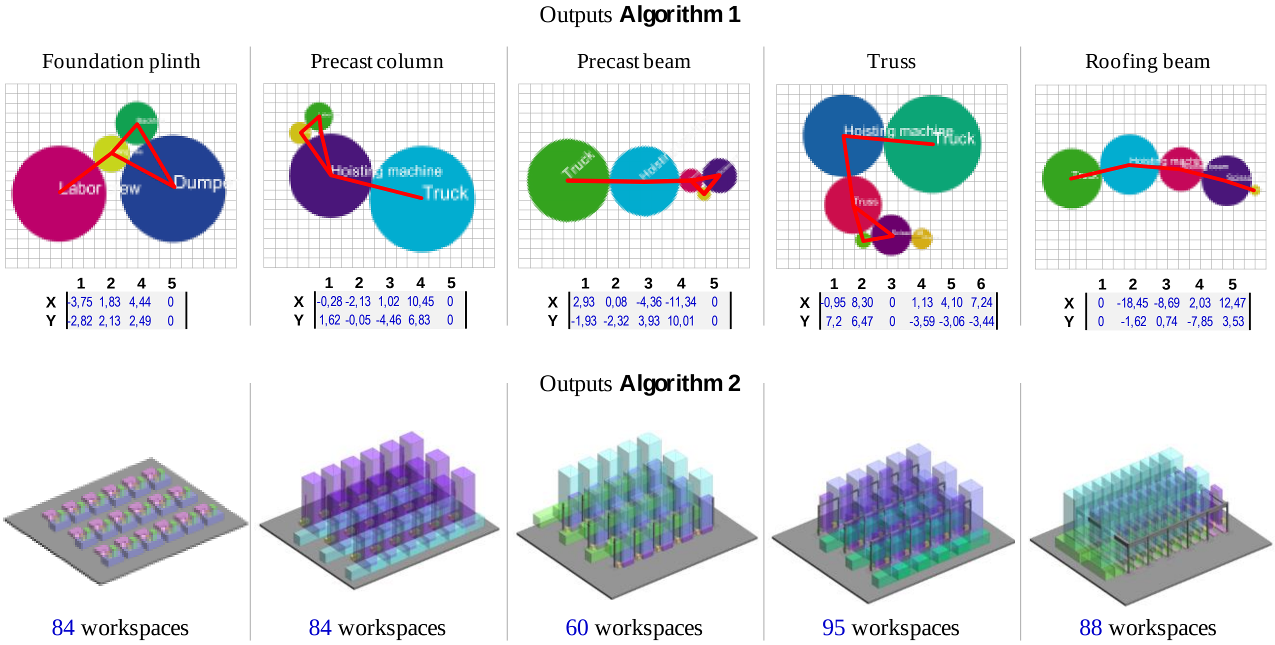

Figure 4. Graphical outputs of the workspaces configuration pattern for the five construction methods

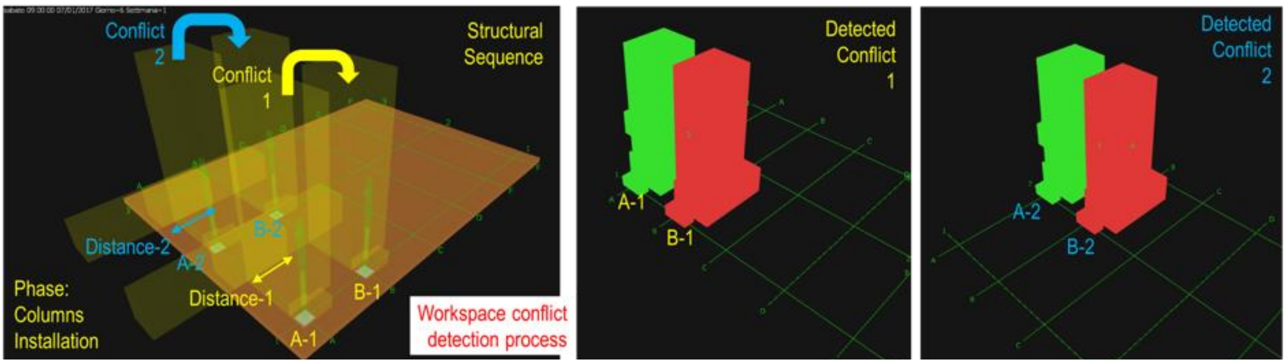

Figure 5. Graphical output of the workspaces conflict detection (*Navisworks Environment*)

In the same environment a scheduling rule is computerized that converts each conflict in a temporal relationship (finish-to-start) among the building objects whose spaces are conflicting.

The generated schedule can be considered the earliest construction sequence in the sense that if one activity will be shifted backwards a workspaces conflict will be detected.

Due to not enough spaces, the proposed workflow as well as the built-in algorithms are basically described in this contribution even if the outputs are presented and a more detailed explanation of the workspaces planning process is presented in the next paragraphs and Figure 6.

4.3.1 Workspaces planning: algorithm to generate the workspaces spatial allocation patterns

The proposed planning workflow is about going from an abstract graph description of workspaces topological structure and their interactions to find their optimal planar allocation with reference to the building object those spaces are linked. The computerization of such a concept has been possible with a built-in algorithm able to manage a parametric design workflow developed in *Grasshopper©*, (a graphical algorithm editor tightly integrated with a 3-D modelling environment). The proposed one is a customization of the one presented in [11]. It main operating steps are below presented and the graphically visualized in Figure 6 for the construction method of precast column installation.

1. **Workspaces graph representation**. As starting point, a number of randomly located points, representing the barycenter of the workspaces, are generated in a CAD environment by using a first operator. At the same time, two dimension values (*has_Lenght, has_Width*) and the identification numbers (*has_ID*) are imported from the external data-base. At this point, a set of operators, first assign colours to the workspaces to make them more recognizable and then generate one circle around each workspaces' center point. Their dimensions are deduced by the rectangular areas of workspaces as suggested by the user in the data-base itself; they are equal. In this way, a first workspaces map representation is generated. This is carried out for each construction methods included in the given BIM.
2. **Workspaces connectivity graph**. Subsequently, the representation of relationships between workspaces is managed by an operator that draws connections -by using a red line- between those pair of points that have a topological interaction (*has_Topological_Interaction*) set by the user within the data-base. The interaction value can be in a rank from 0 -*no interaction*- to 5 -i*ndispensable interaction*-.
3. **Space Syntax Analysis**. Having generated the connectivity graph, according to the space syntax analysis, an operator re-distributes the workspaces (circles) on deph-levels. A *depth* is the smallest number of syntactic steps (in topological meaning) that are needed to reach one space from another. Therefore, depending on the number of workspaces that each construction methods contains -e.g. five spaces for the column installation- one configuration for each space by using depth levels is generated. It represents the point of view of a labourer getting in position in that workspace on 'depth-0'. The generated graphs are used for a visual validation from the construction manager (user) who has defined the workspaces requirements in the data-base itself.
4. **Generation of the workspaces allocation pattern**. Once the model is provided with workspaces connectivity values, the algorithm contains a force-directed graph-drawing operator which is able to generate a bubble diagram representing the optimal workspaces allocation pattern based on user-constraints set in the data-base. This function works translating the interaction values between workspaces (*has_Interaction_Value*) in a set of attractive forces. The forces act recursively on the graph vertices, seek a 'relax' situation for a graph, and provide the system with a graphical representation of the given solution. The output is a bubble diagram -once again one for each construction method included in the model- compliant with the specified workspaces dimensions and the connectivity values.
5. **Extrapolation of workspaces spatial coordinates**. Once a workspaces configuration pattern is deducted, the spatial allocation coordinates -on the X-axis and Y-axis- from the bubble diagram are extracted and stored in the external database. The model considers those workspaces as located at the same height (Z-axis) of their connected building object.

5 Discussion and future development

The obtained results show how the layout allocations of spaces cannot be considered never fixed but they strictly depend on both the chosen construction method and planning rules. Infact, the space syntax analysis, carried

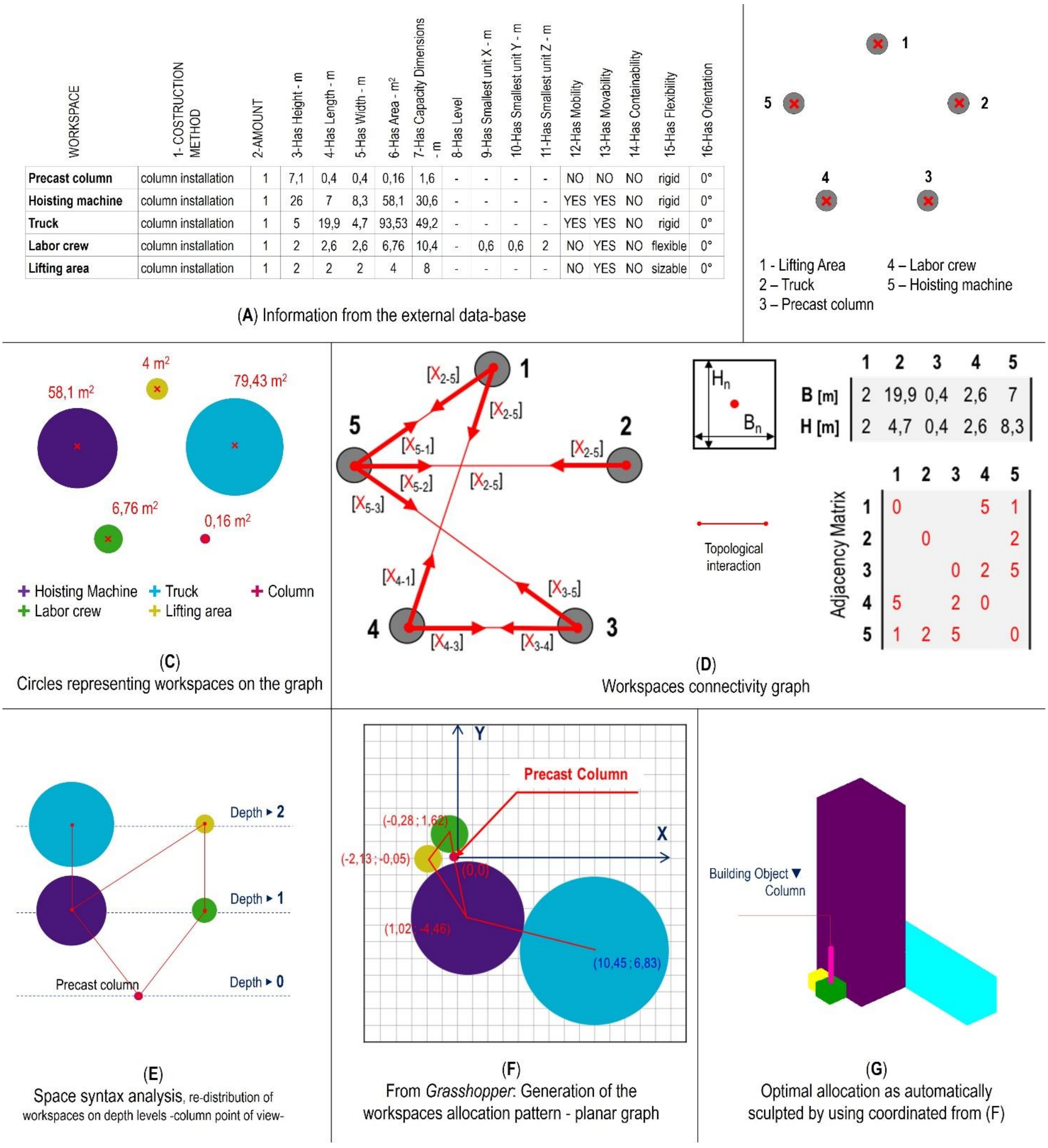

Figure 6. Workspaces planning process: Construction method of precast column installation

out on five different construction methods, demonstrated that even if workspaces had the same dimensions, their layout allocations may be different depending on their relations as well as their interaction values.

Moreover, it demonstrates how important should be the integration of human experiences even in BIM-based scheduling models as well as the pretty unbreakable bond that exists between a construction schedule and the spatial allocation of workspaces and their topological interactions.

The proposed workflow, supported by the two integrated algorithm, was capable to plan and model 611 workspaces by binding the scheduling process to them (Figure 7). The same process would be unsustainable if manually managed or without a holistic and digitized planning process. This requirement increases if we think that if some changes occur (e.g., construction methods, workspaces, building product dimensions, etc.) all the entities should be modelled again. The presented construction scheduling workflow is a part of a wider research project the author are working on that aims to develop an *BIM-based Expert System* supported by an ontology based system architecture (for semantic modelling the construction process knowledge) integrated with a rule-based artificial intelligence (for workspaces management and schedule generation).

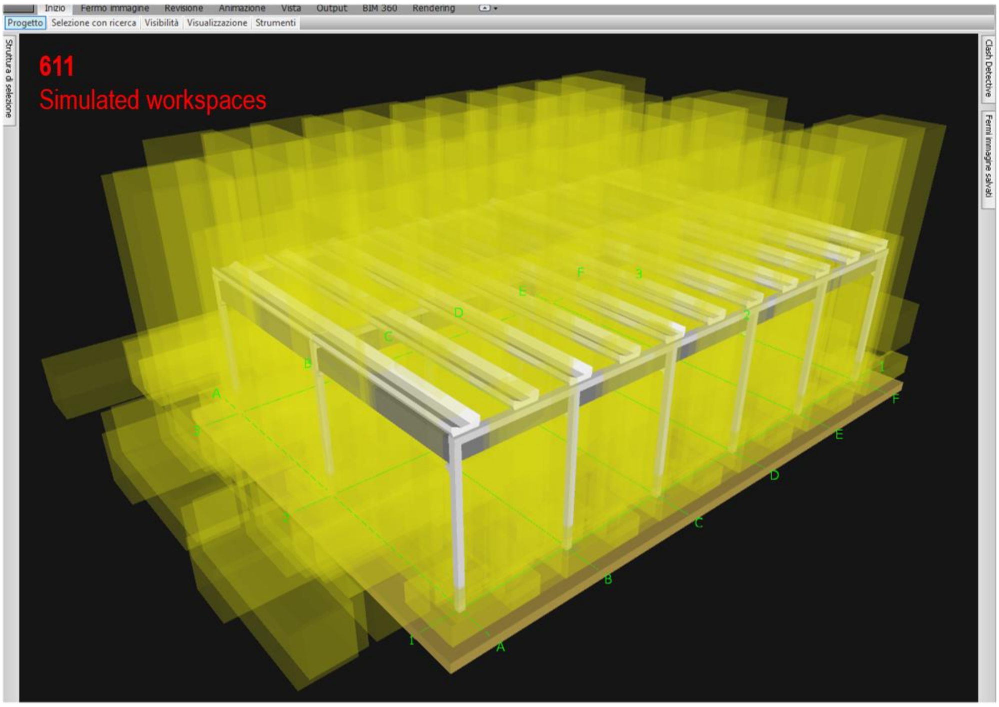

Figure 7. BIM-based site digital prototype with all the required workspaces to construct the building objects

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