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# ASSISTED ANALYSIS ON WORKS INTERFERENCES ON RESTORATION CONSTRUCTION PROJECTS

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## Abstract

Workers' safety management in restoration construction sites is an arduous task for designers since the difficulties given by particular environment and the wide range of works existing in the restoration panorama. In order to properly face this task, construction site needs to be studied since the preliminary phase of the design process, especially in restoration where work processes has a great influence in the success of the intervention. In fact this preliminary study on operational issues is able to solve a great number of criticalities that affect the project, if discovered during works, in terms of time, cost and worker's health and safety. In particular works interference analysis is an important challenge to void delays due to the overlapping of works in adjacent spaces. In order to facilitate this task the ongoing research developed an IT based method for construction site interferences analysis. The main mission of this method is to assist the choice of the right action to solve interference criticalities. The system is primarily based on the storage of typical construction work places in a database and it is supported in particular by BIM tools and spreadsheets linked together. That way is possible to have a simple access to information required for interference analysis such as potential damage for workers and feasible technical solution. This amount of graphical and informative data permits to foreshadow interference situations in a restoration work and to automatically find, thanks to a proper data match, possible solutions of the analyzed interference to be chosen by the site designer.

**Keywords:** Restoration site design, interference analysis, risk assessment, BIM, CoSIM

## 1. Introduction

Safety evaluations on construction sites are important tasks to be faced during design phase, not only by the site designer but also by the whole design team, as law requires. In restoration projects this task is certainly more arduous to face, since the intrinsic uncertainty given by the particular context of an existing building. If not promptly studied during design phase safety issues could extremely affect the project especially in restoration where work processes has a great influence in the success of the intervention. In fact, a preliminary study on operational issues is able to solve a great number of criticalities that could affect, if discovered during works, the project in term on time, cost and worker's health and safety. One of the most important task for a site designer is the evaluation, and then the resolution of interferences between working areas of the construction site since the need of coordination between different construction firms. In fact times and costs evaluations require frequently the realization of different works simultaneously with the presence of different firms on the same place at the same time. A correct evaluation of the interferential risk is always an arduous task for a site designer since the unpredictability of site situations and the number of possible interferences that could occur in each construction phase. Since these difficulties, detectable especially in restoration projects, the presented research aims to develop an IT based method for construction site interferences analysis and resolution, if possible, by the insertion of proper site technical elements that could avoid the interference. The development of this system fits in a wider research on the BIM implementation for construction site design that aims to make more efficient all aspects of site

planning. Therefore, the proposed system is primarily based on BIM tools used for site design linked together with spreadsheets for a faster information management. As the application on a real case study will demonstrates the developed system permits to foreshadow interference situations in a restoration work and to automatically find, thanks to a proper data match, possible solutions, to be chosen by the site designer, of the analyzed interference.

## 2. Literary review

The recent spread of BIM AEC Industry took the research to examine widely different aspects of this technique with the aim to improve step by step efficiency in building design and management. Although a large part of the research focuses primarily of aspects related to new construction, in the last years the focus on restoration projects improves. A great work in focusing BIM research for existing building was carried out by Volk et al. [1]. In particular they observed in a wide literary review a "scarce BIM implementation in existing buildings" both from industry and from research points of view. The main reasons of this scarce development could be the not yet solved difficulties in conversion of existing matters into BIM objects and in reaching certain data of already realized buildings. In addition, many studies and researches applied in existing building have been taken into account maintenance and facility management of recent structures rather than architectural heritage. The development observed in BIM research concerning existing building takes into account a trend that is named by further researchers as HBIM (Historic Building Information Modelling) or, in some cases, BHIM (Building Heritage Information Modelling). In particular, the improvement of 3D survey techniques such as laser scanning facilitate the diffusion of HBIM since the possibility to have at disposal a precise 3D survey to be translated in BIM. In this sense, Murphy et al. [2] aim to create a "prototype library of parametric objects" starting from the collection of survey data in order to produce complete architectural 3D models not only characterized by surfaces but also by parametric information (e.g. construction methods). Conversion of such particular objects concerning historical buildings (e.g. classical orders columns) into parametric objects has been a great challenge to face, due to distinctiveness of many elements [3]. Another challenge is to represent actual conservation conditions of an object in order to manage possible maintenance/restoration intervention. Oreni et al. [4] follow this way, studying HBIM for several aspects, starting from model render of 3D survey to make it interoperable for conservation and restoration management. From this points of view is possible to start to think about operational issues of a HBIM in order to properly produce a site design. Academic research analyzed many different aspects of site and works planning trying to implement it in a BIM environment. However the largest part of this concerning with new construction rather than restoration and recovery. Vimonsatit et al. [5] underline the possibility to enhance site planning thanks to simulations and BIM that shows available spaces throughout the construction stage. However this research focuses on a problem on a lack of serious design tools that do not leave the choices entirely to the knowledge of the users. Lot of the researches the concerns construction sites are indeed focused on construction scheduling (with the implementation of 4D models) and safety planning. In particular from many years researches on 4D scheduling have been carried out starting from 4D CAD tools [6] to 4D BIM and use of data to generate schedules [7]. The 4D tools and the resulting possibility of construction phases visualization permit a detailed design of construction works taking into particular consideration, first of all, safety aspects. However planning for safety has been considered an important task in the satisfaction of the project needs. For what concerns site spaces management Kassem et al. [8] focused their attention on the development of a 4D tool able to visualize in time working space in each BIM environment since the compatibility with IFC. A further improvement was given by Moon et al. [9] who focused particularly on interferences underlined by schedule. In general the main goal is to facilitate safety planning production [10] ensuring a detail level suitable for hazard identification before starting construction. The presented research aims to the same objectives by give an overview of the construction site design process and developing a coherent method supported by proper tools able to help the site designer in his tasks. One of these tools -specifically developed for the purpose by the task group of A.B.C. Dept.- consists in the presented IT system for working spaces interference analysis.

## 3. Research method and background

The presented research takes into consideration a solid background developed during years about construction site planning and management. It consists in particular on some principles, in continuous development thanks to research on the topic supported by many direct experiences carried out especially in relevant restoration construction sites. These experiences permit to get and remain in touch with the developments of professional work to whom our research activities is dedicated. For this reason, our research method consists in simple circular path that starts from the on-field observation for research development to the on-field application of the research (see figure 1). In fact our research aims mainly to facilitate and make more efficient the work of designers in terms of on field feasibility of work and construction site planning and operation.
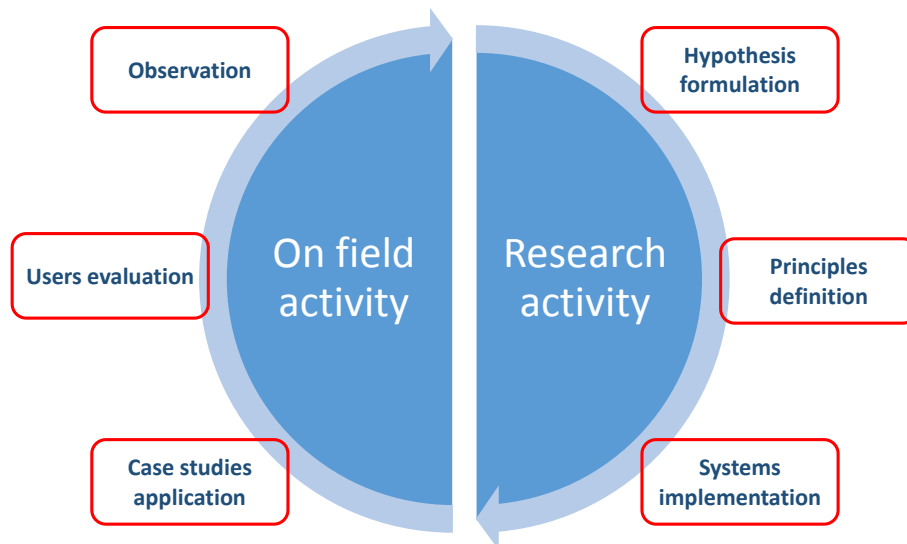
Figure 1 – Research method as a circular path

Thanks to the experience given by a direct on-site observation is possible then to make a system between the developments of the research and the increasing needs of designers in order to develop methods and tools for enhance efficiency to site planning and management of restoration projects.

The field analysis permits also to have at disposal different case studies useful for testing implemented system and evaluate their efficiency of, if necessary, to refine them. Tanks to this approach we developed step-by-step many issues related to construction site design of existing project concerning also, especially in the last years, IT tools use and implementation. One of the last research reports [11] developed in particular a proper methodology for BIM use to achieve operational planning on existing building projects realizing a proper Construction site information model (CoSIM) [12]. It concerned in particular the interaction between designers during the whole design process (starting from the survey, to the operational planning, through architectural, structural, MEP and other design disciplines). In particular that part of the research focused in the modelling processes of a heritage building in order to guarantee a correct element level of development (*i.e.* an adequate graphical detail and number of related information - LOD) for operational planning. The method concerned also the insertion in the model of construction site elements (*e.g.* equipment, machines, temporary structures) in order to study working places development during construction time and evaluate construction time, costs and safety issues.

The element choice for construction planning is always an arduous task since it involves different concerns from time, costs and safety points of view. In order to facilitate this operational design step, our research frame the construction site as a system [13] divided in sub-systems with precise functions for the satisfaction of the construction site needs. We can define the following three principal sub-systems:

- The technological system
- The productive system
- The functional-spatial system

The technological system represents the set of technical components useful for the realization of a particular working phase. In particular, they represents all the temporary facilities needed in a construction site (*e.g.* scaffolding, fences, etc.).

The productive system represents the set of productive elements useful for the realization of a particular working phase. In this system are grouped all the equipment or machines related to the production in construction sites (*e.g.* cranes, trucks, etc.).

The functional-spatial system is then made of the spaces needed in the construction site with their own specific functions (*e.g.* Logistic Spaces, Production Spaces, etc.).

Our research on BIM use for construction planning contemplates the modelling of a reasonable number of these elements, taking into particular account that related to restoration and recovery projects.

On this basis, we develop some specific tools able to simplify and assist operational choices during construction site planning. Since the particularity of restoration project that creates a lot of interference between working-places, is here presented the tool to assist the choice of safety devices to solve these interferences.

## 4.  Overview on the developed method

Starting from the issues underlined in the previous paragraph the proposed method develops in particular the functional spatial system, but takes into account also the others since the strict relationships between them. In fact, as said, the system is based on the study of interferences between different spaces of a construction site and its boundaries. To do this the first step concerned in the identification and modelling of an adequate number of typical site space that could cover the range of possible places needed in a restoration construction site. The models consist essentially in a parametric (with changeable dimensions) surface that identify the standard spatial elements. Each type of surface was then inproved by a symbol that identify the specific function of the space and colored to make it visible compared to the others (see figure 2 for examples of the BIM related to spatial element). Table 1 shows the 7 different types of studied places with their own characteristics.

| Spatial element | Function symbol | Identification colour |
|---|---|---|
| Working place | Concrete mixer and stored bricks | Red |
| Aerial handling place | Tower Crane | Purple |
| Excavation | Excavator | Orange |
| Walking path inside construction site | Worker | Green |
| Vehicle path inside construction site | Truck | Blue |
| Public walking path | Pedestrian | Yellow |
| Public street | Car | Grey |

Table 1 – Construction site spaces types

Once identified the space types, in order to study the construction site interferences, an inventory of combinations between two of this spaces has been created in order to cover the largest possible number of interference configurations. To do this each type of space has been related to the others at the same level, or at a different height. Furthermore, each configuration has also a semitransparent shape that identifies the interference volume to be taken into consideration. In fact this volume will be replaced, during design process and with the assistance of the proposed system, by a proper safety device. The result of this research step is an inventory of 70 modelled standard configurations similar to the 7 showed in Figure 2 and here explained:

a) Interference between a **Walking path inside construction site** and **public street** at *the same level*
b) Interference between a **Working place** and **Vehicle path inside construction site** at *a different level*
c) Interference between a **Walking path inside construction site** and **Vehicle path inside construction site** at *the same level*
d) Interference between a **Public walking path** and **Working place** at *the same level with another place in the middle*
e) Interference between an **Aerial handling place** and **Working place** (aerial handling places are always considered *higher* compared to others*)*
f) Interference between an **Walking path inside construction site** and **Excavation** (excavations are always considered *lower* compared to others*)*
g) Interference between a **Working place** and **Walking path inside construction site** at *a different level*

All these models are included in the proposed system in order to facilitate the identification of interference and to have at disposal an inventory provided with ready solutions.
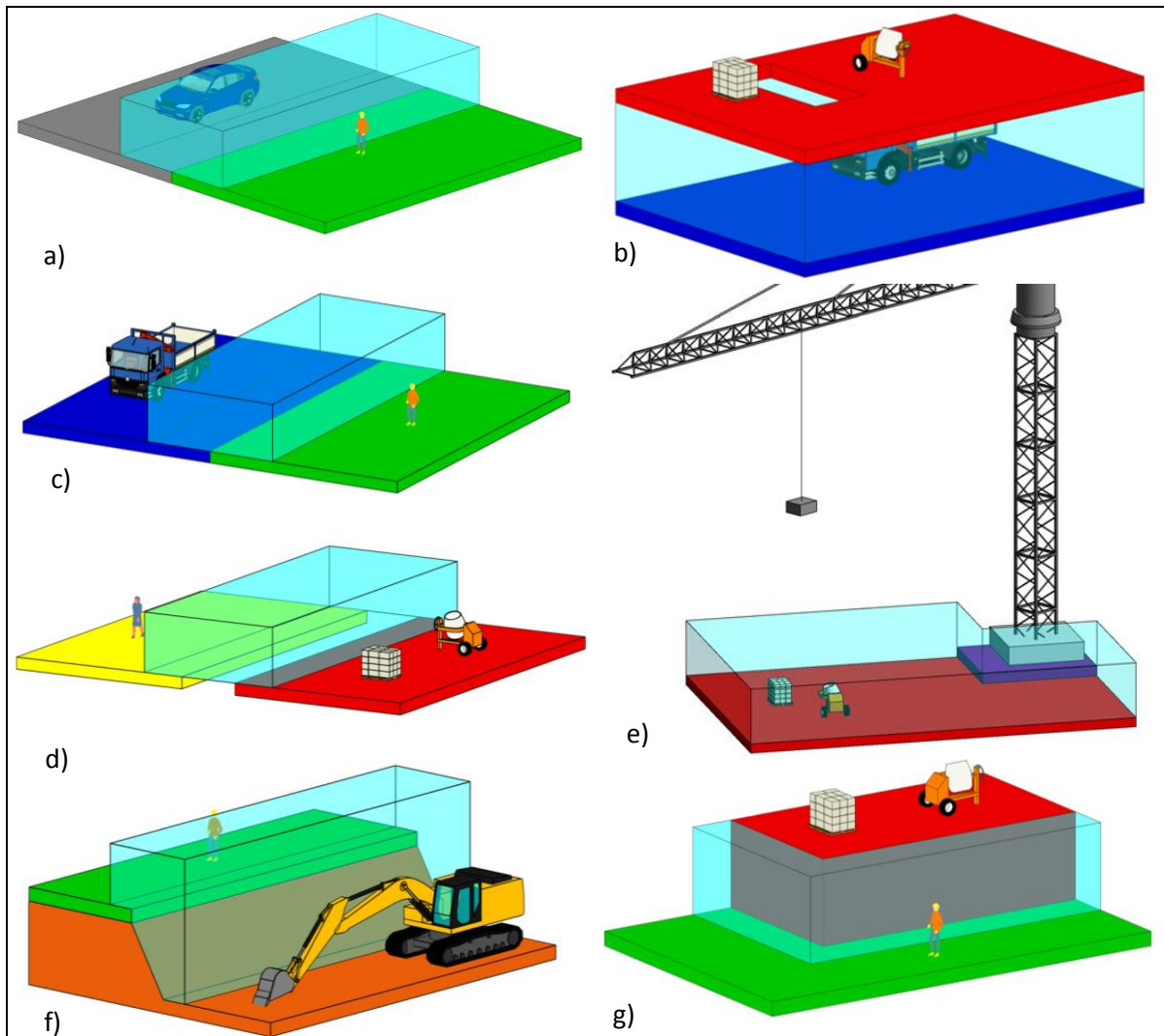
Figure 2 – Examples of interferences configurations between spatial elements

The modelling work consists also in the creation of a number of technological elements (such as fences, guardrails, etc.) able to technically solve the interference and so to replace the semi transparent shape. As said in addition to the BIM method the system is based also on spreadsheets linked together in order to have a simple access to information required for interference analysis such as potential damage for workers and possible technical solution. In other works the spreadsheets permit to access to a database of technical solutions able to solve the interferences underlined in the different studied configurations. The spreadsheets is provided of a searching tool that permits to automatically select a solution according parameters to insert as an input (potential damages founded in the real construction site situation. In order to better understand the whole process of selecting the solution a workflow is provided in figure 3. It explain the process of solving interferences from a site designer point of view during a real design process explaining the steps of his task.

The first step consists in the initial modelling of the construction site with the identification, in function of the available spaces, of the functional spatial organization of the construction site. Thus, once available the Survey HBIM [11], the first task is to add to the model the colored surfaces with their specific functions. As will be showed in the case study (see next paragraph) this task need to be faced for each construction site phase since the site configuration changes during time. The second step is the identification of the interferences between the identified places that have to be searched in the inventory of created configurations. Each configuration has, as related information, a range of possible damages given by the interference. Damages represents the input for the spreadsheet searching tool. Obviously, during data input the potential damages can be changed or added according to the designer risk assessment according to the particular site situation. In fact, although the inventory of configuration has been created taking into account on-field observations during restoration projects, it is obvious that these kind of works have always a certain level of unpredictability. Thanks to the input of potential damages in the spreadsheet, the searching tool select those solutions able to avoid those specific hazards in that particular condition. It is then a task of the site designer to choose between the proposed solutions according to his experience and the other situations studied in the area.
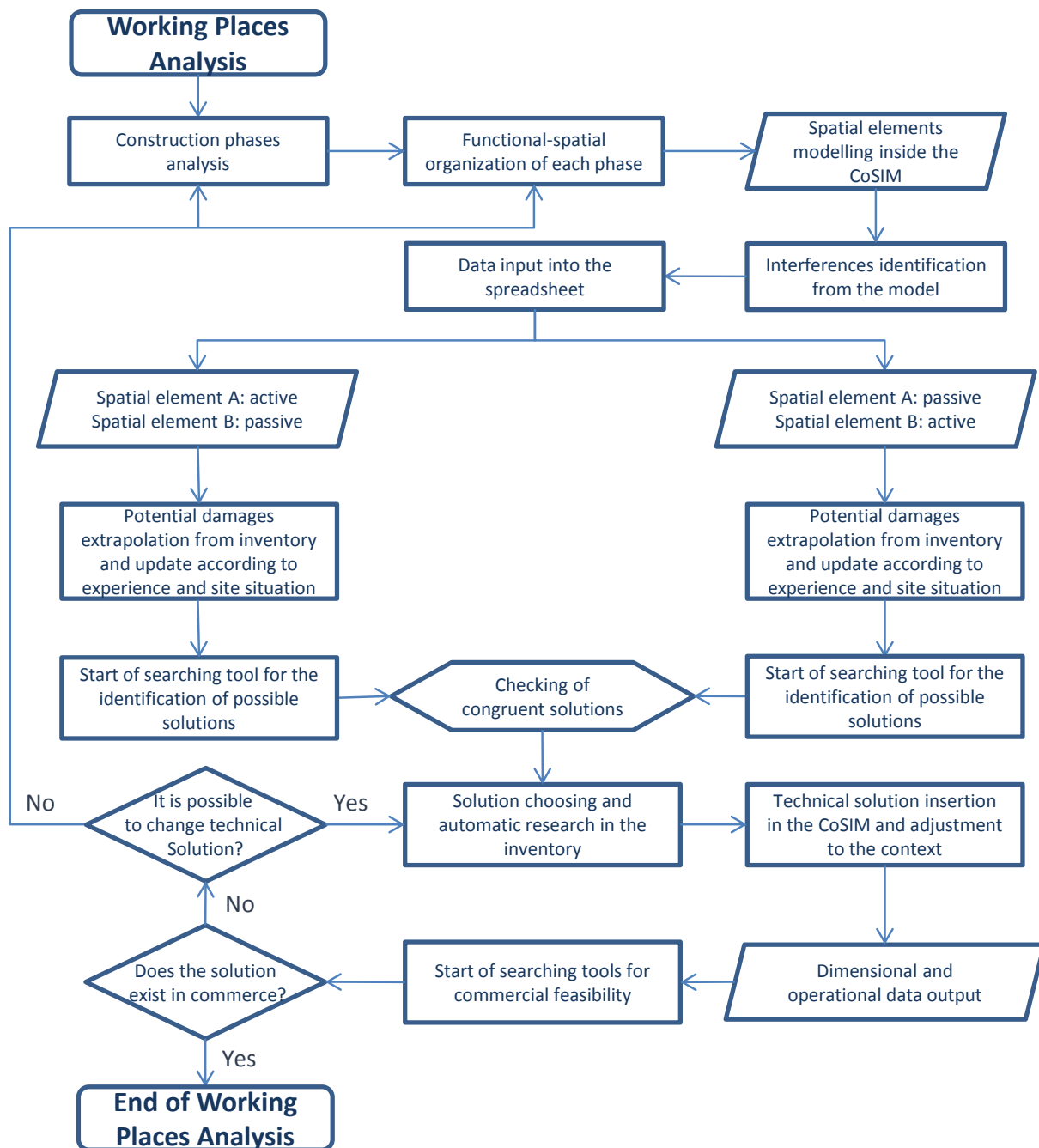
Figure 3 – Design workflow for the proposed system

Figure 4 shows the input panel of the searching tool. It is divided in two parts since the need to take into consideration the possible damages in two directions. In fact hazards could occur from a space to the neighboring and vice versa. The first data inputs concerns the type of places and their position, and permits to search in the inventory of configurations the correct related to site situation. An image from the inventory appear to make clearer the choice. The choice of the configuration take to the second sheet (Figure 5) in which possible damages are visualized according to the explained standar-dization. As said, the site designer can change them according to its experience. For each potential damage the system proposes a technical solution to avoid hazards. At the end, the congruent solutions between the two directions of interferences automatically appear in the last cell and the site designer can make the final choice. This choice automatically appear in the image in substitution of the interference volume. It is also related to the BIM model in the inventory so it's possible to take the solution and put it inside the CoSIM in order to evaluate the general site situation. The inventory of technical solution is in fact created as parametric elements that can be simply suite each site situation and contain useful data design evaluations. Some of this data represents the inputs for the last spreadsheets that permits to evaluate the feasibility of the choice. In fact it permits to search in a database of commercial solution if the technical elements is really possible to realize on field. [14]

| Passive spatial element (subjected to a damage) | a | Walking path inside construction site |
|---|---|---|
| Active spatial element (generator of a damage) | b | Excavation |
| Mutual position | | Ha>Hb |

| Passive spatial element (subjected to a damage) | b | Excavation |
|---|---|---|
| Active spatial element (generator of a damage) | a | Walking path inside construction site |
| Mutual position | | Ha>Hb |

3D PREVIEW
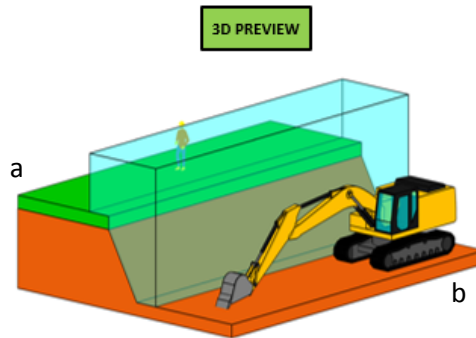
Figure 4 – Input panel of the searching tool

| Potential Damage | Technical solution |
|---|---|
| E12 – Grabbed by boom | Steel fence |
| E13 – Hit by excavated materials | Guardrail |
| E26 – Falling down into the dig | Guardrail |

| Potential Damage | Technical solution |
|---|---|
| E13 – Hit by falling materials | Guardrail |
| | |
| | |

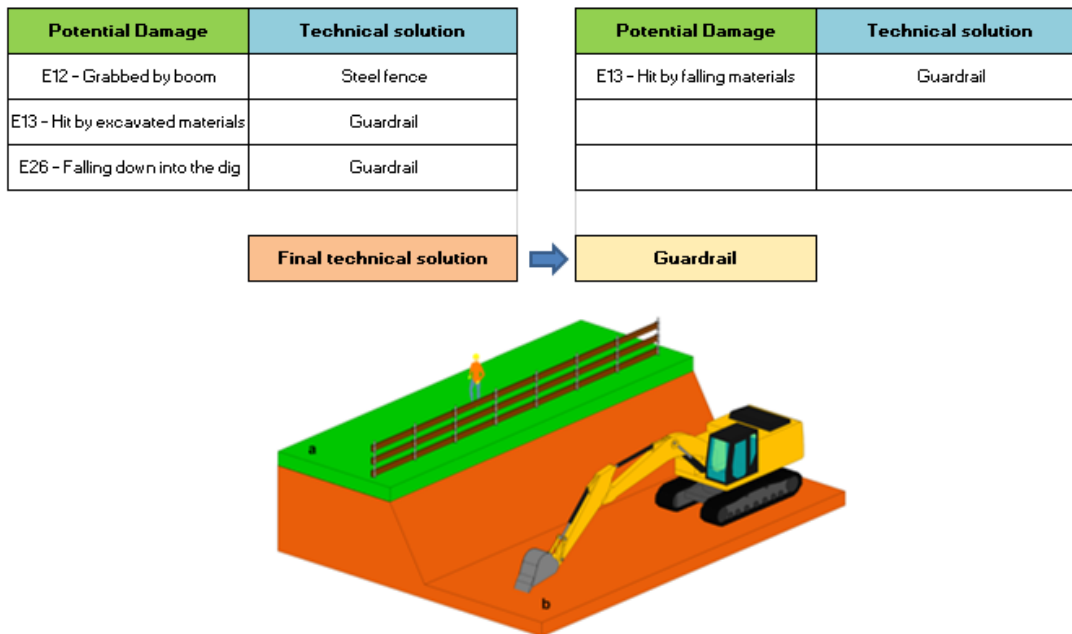| Final technical solution | Guardrail |
|---|---|

Figure 5 – Output panel for potential damages and final choice of the technical solution

## 5.    Application on a case study

The cited early report of the research [11] presented the case study of the restoration of Basilica di Collemaggio (L'Aquila) and focused on the modelling process of the building elements in order to realize a proper operational planning thanks to the related information attached to the elements themselves. The following part of the CoSIM design process is here presented. In fact, once produced the work plan thanks to the above mentioned information, is necessary to analyze working-places in order to evaluate, and eventually optimize site planning in terms of time, costs and safety. The proposed system permits to make at the same time the analysis and the optimization of working-places at the same time.

Figure 6 shows an overview of the Church that presents significant damages produced by the earthquake of 2009. Due to particular structure of the church, earthquake affected primarily transept area, with the collapse of two main pillars and consequently of the central dome, that is now covered by a metal-structure roof. Also octagonal columns and walls of the naves were subjected to a lot of damages so that, just after the earthquake, in was necessary to reinforce that structures with temporary facilities (see figure 6b)

Figure 6 – External and internal overview of the basilica before works

Restoration works have been promoted and funded by ENIservizi and have involved "Soprintendenza per i Beni Architettonici e Paesaggistici per l'Abruzzo", "Politecnico di Milano", "Università degli Studi di Roma, La Sapienza" and "Università degli Studi dell'Aquila". Intervention concern in particular the reconstruction of the transept and structural rehabilitation of columns, walls, and roofs. Surfaces restorations and plants will be the final activities to return the church to the city of L'Aquila. As said the first part concerned the insertion in the model of operational information and their management for scheduling works taking into account many contemporary activities and to calculate and optimize costs for the realization of site facilities such as fences and scaffold. Then CoSIM design continued with the visualization of the sequences of contemporary working-places studying thus actions to be performed for workers safety thanks to the described method.

Figure 7 shows in particular the starting situation of the working spaces inside the basilica during one of the construction site phases. As the figure shows, there are 5 contemporary works inside the area and as well as a pedestrian and a vehicle path. The number of contemporary work is explained by the need to finish soon the works and to open the church to public in few time. Since the quantity of places studied, interference volumes are hidden in the figure in order to have a better visualization of the situation. For the same reason identification of the working places are here made by the specific colour (red) and a worker instead of concrete mixer.

So the internal area of the basilica presents some facilities that are the same for the whole construction site (e.g. the vehicle path inside construction site in the middle of the central nave) and some areas specific of the construction phase (e.g. working areas). Obviously, thanks to 4D tools the presented study was performed for each construction phase in order to properly manage interferences during the whole construction stages and correctly calculate the total extra costs given by the insertion of proper technical solution between adjacent places.
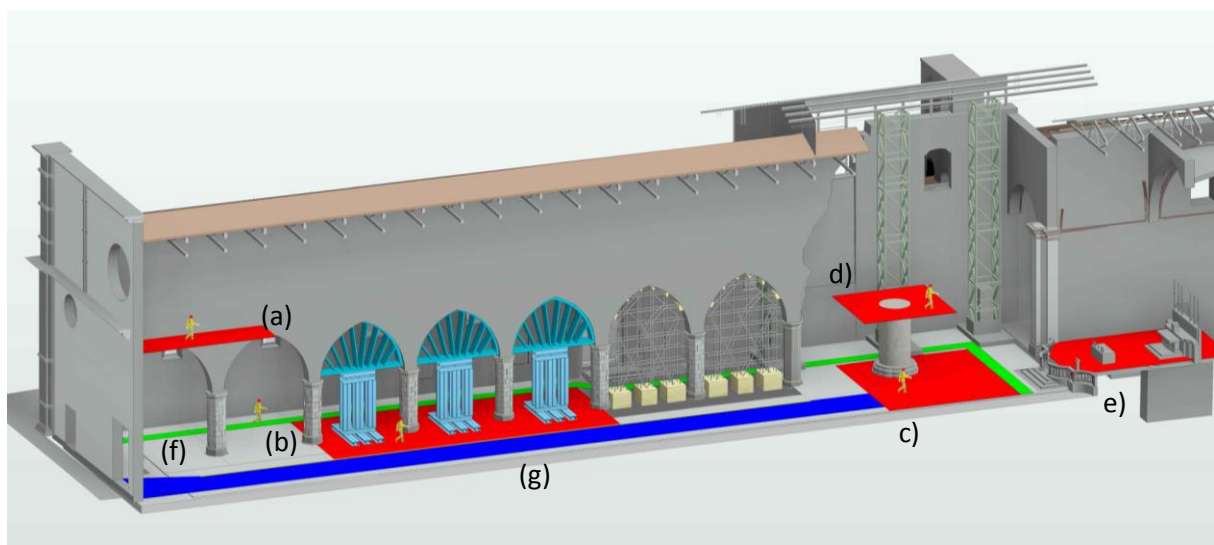

Figure 7 – 3D view of the different place of work inside the church needed for a specific phase

For each phase the study followed all the steps described in the previous paragraph for the extrapolation of possible technical solutions for each interferences between a couple of places. These single solutions have been inserted in the model for the final evaluation on choice. Table 2 shows an

overview about the solutions for single interferences while figure 8 shows the final configuration of the construction site for that particular phase. In this case some temporary structures are simplified in order to have a better view on the places of work (for example some part of the scaffolding such as guardrails are hidden in the 3D view).
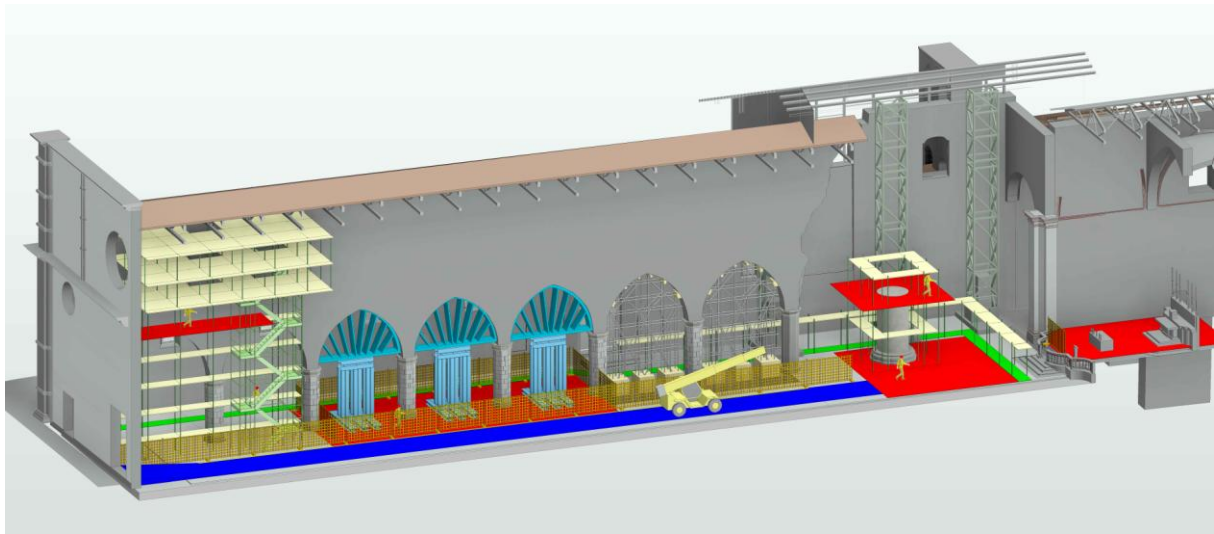


Figure 8 – 3D view of the different place of work and technical solution for interferences

| Spatial element 1 | Spatial element 2 | Position | Solution |
|---|---|---|---|
| Working place (a) | Vehicle path (g) | (a) In height on (g) | Scaffold |
| Working place (b) | Vehicle path (g) | Same Level | Steel fence |
| Working place (b) | Pedestrian path (f) | Same Level | Steel fence |
| Working place (c) | Pedestrian path (f) | Same Level | Fence on the scaffold (Hidden in figure) |
| Working place (d) | Working place (c) | (d) In height on (c) | Scaffold |
| Working place (d) | Pedestrian path (f) | (d) In height on (f) | Continuous protection roofing (added also for other workplace in height in following phases) |
| Working place (e) | Pedestrian path (f) | (e) In height on (f) with a gap | Steel fence |

Table 2 – Summary of the interference analysis between the places of work

## 6.    Conclusions

The proposed methodology suit perfectly to the chosen case study since the yet expressed need to have many contemporary works during the whole construction process. Thanks to the use of this method such advantages has been observed in the developing of the site layout for each phase of the construction site. First of all this method helps a lot to graphically identify the different places of work in such a chaotic context. Since the models of the different places are ready and parametric their positioning results very fast and efficient and thus each phase can be simply managed. For what concerns the addition of technical solutions it's obvious to say that an experienced site designer can chose the solution using its own knowledge. However in such an intervention, in which are present a lot of interference for each phase, the availability of the inventory and of the searching tool results helpful in particular for what concern the following points:

- To have a standardized evaluation method for each interference
- To make faster the research among the inventory of BIM elements to put into the CoSIM
- To have at disposal some ready risk evaluation sheets to update only if necessary
- To make faster the production of safety documents thanks to the availability of this sheets

Obviously, the system results more useful and efficient if the construction site is very complex. For this reason, as the case study demonstrates, it fit particularly with relevant restoration projects. As a future development, we take into consideration the possibility to manage the choice taking into account more than two spaces for configuration. In addition to this we are updating the spreadsheets in order to evaluate different configuration together if necessary in order to be congruent with chouces in the whole construction site. Obviously, in order to make more efficient this system and the whole CoSIM design some more steps need to be carried on. As an example the availability of construction site objects among libraries is still poor. Furthermore, their level of detail is often inadequate both from a graphical and from an information point of view.

Despite of this, the field test encourage the task group to continue in this research in order to spread as much as possible CoSIM method and realize the aim of raise construction site planning to a clear design discipline to be faced since the first phases of each project.

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