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Editoriale
Editorial

Construction Management Workshop 2018

Marco Bragadin
Kalle Kähkönen

This workshop on Construction Management (CMW18) follows the preceding edition in 2013, again in Ravenna, concerning new research themes and fields of innovation for construction management. The workshop of 2018 focuses on possible and future implementation of digital technologies in the building sector, generally addressed as industry 4.0. This is to be addressed without forgetting other important drivers of change in the societies, business environments and in the real estate and construction sector (REC) itself. The environmental concerns and climate change are already now sources for large scale regulatory changes. On the long run the overall performance of the REC sector shall play a major role in tackling the environmental challenges. This will be also construction and real estate management challenge. The performance of the sector can be improved only via large scale systemic changes and innovations.
Industry 4.0 is the current name of the actual trend of automation and data exchange for production processes of manufacturing industry.

Industry 4.0 describes the organisation of production processes based on technology and devices autonomously communicating each other along the value chain (EU, 2016).

It includes Cyber-Physical Systems, Internet-of-Things, Cloud Computing and Cognitive Computing. By this means Industry 4.0 technologies aims at implementing the "Smart Factory", an intelligent factory where Cyber-Physical Systems monitor and control real productive processes by creating a virtual copy of physical world, and take centralized and informed decisions. Cyber-physical systems communicate and co-operate with each-others, and with humans, in real time both inside the production process and outside it with all participants of the value chain, form owners to final clients. The revolutionary idea is to create a simulation of the physical system by creating a Cyber-Twin, a virtual systems that simulates the behaviour of the real one, to improve the monitor and control process by means of sensors and actuators. By integrating the two systems, physical and virtual, an intelligent system is created. This integration of the two worlds, the physical and virtual one, gives new future development possibilities that go far beyond the perspective of traditional automation technologies.

The name Industry 4.0 refers to the fourth industrial revolution, and originated by a strategical vision of the German government that aimed at promoting the computer use in industrial applications, presented in the Hannover exhibition of 2011 (Kagermann, Lukas, Wahlster, 2011).

The fourth industrial revolution concerns a series of disruptive innovations in production and leaps in industrial processes resulting in significant higher productivity. It is viewed as the fourth time such a disruption took place following the preceding industrial revolutions. The first Industrial revolution developed in the late 1700s in Europe and America when steam power combined with mechanical production led to the industrialization of production. The second industrial revolution when electricity and assembly lines resulted in mass production from the mid-1800s onwards. The third industrial revolution when electronics and IT combined with globalisation greatly accelerated industrialization since the 1970s (EU, 2016).

WORKSHOP THEME

Recent theories concerning the 4th industrial revolution "**Industry 4.0**", indicate that the digitalization of building construction processes can open new research perspectives and themes for the development of the construction industry, particularly in the field of **Construction Project Management**. The theme of Construction Management in the building project life-cycle phases (design, execution and operation) is of capital importance for the economic recovery and development of the construction sector, an industry sector that still struggles to recapture the pace and find a new identity and future perspectives. Surely, the theme of the **Smart Factory** causes to focus on the building process and its different **Value Chains**, aiming at the creation of a more efficient connection between its players: client/final user; owner; designers; construction companies and their suppliers.

In the research environment created by the collaboration of the research group of building production of the University of Bologna and the one of **Construction Management and Economics** of the Tampere University of Technology of Finland, this workshop has the aim of highlighting the research themes that could develop the drivers of change and innovation in the project management processes of design, construction and maintenance.

The research themes to be investigated could facilitate the innovation process and the development of the "**Smart Factory**" in construction, aiming at creating a "**Smart Building Site**" for construction projects. The objectives are many: implementation of the circular economy principles, orientating towards the improvement of building life cycle environmental and economic sustainability; improvement of process efficiency of the value chains through the development of innovative methods and tools that will improve the design and the execution of building projects; improvement of building life cycle-based design to optimise costs and impacts of operations and maintenance.

Anyway, the overall workshop theme is Construction Management. Construction management is an internationally recognised area of research. Its origins can be surely found in an extension of operations management in the construction sector, but now it has a broad and heterogeneous body of knowledge that improves its aims and scope (Harty, Leiringer, 2017).

Bennett (1983) proposed a conceptual framework for project management in construction, based upon two distinct phases. The first phase is strategic, being concerned with client objectives, project description and organization. The second is concerned with the execution of basic construction tasks. Also it is recognized that there are sets of co-ordinated human activities aimed at defined objectives, called projects, that tends to be one-off non-routine undertakings with discrete time, financial, and technical goals. The objective of construction projects can be the completion of a building, an industrial processing plant, a bridge, or some other physical object and at the same time the organization arrangements designed to ensure the efficient completion of the project. This is translated into objectives of producing quantities of accommodation, the quality of that accommodation, its cost and the time to be delivered (Bennet, 1983).

Considerable amount ofresearch and development effort has been made towardsthis direction, and many intellectual roots of project management research have been discovered (Söderlund, 2004). The first and the most important seems to have its origins in the various types of planning and scheduling techniques, such as Gantt chart, CPM, PERT and Precedence Diagramming (Gantt, 1919; Moder, Phillips and Davis, 1983; Wren and Bedian, 2009). Beside this, project management has its origins also in temporary organizational forms (Lundin, Söderholm, 1995). Two different bodies of knowledge seem to be the intellectual roots of project management. The first is engineering science and applied mathematics, primarily interested in planning and scheduling techniques and methods of project management. This line of research would indicate project management as a specific problem-solving method based on project activities' understanding, grouping, planning, scheduling and controlling. The second has its intellectual roots in the social sciences, such as sociology, organization theory and psychology, and it is primarily interested in the organizational and behavioural aspects of project organizations and in organizational theories.

Nevertheless, in the end, it is believed that projects are nothing else than a way of looking at industrial and organizational activity (Söderlund, 2004). Consequently, research into project management can follow one of these two lines, or both. It is a matter of trying to capture the "unique, complex and time-limited processes of interaction, organization and management" (Söderlund, 2004). These management processes can be further divided. The conceptualization of project management theories by Koskela and Howell (2002) in fact, divides the Project Management Body of Knowledge (PMBOK) mainly in two parts, the project theory and the management theory, respectively the work needed to achieve project objectives and work needed to organise and develop project management processes.
With the presented perspective we can expect to see multiform and

multidimensionaloutcomes from research work and development in the field of Construction Management (Harty & Leiringer, 2017), but the intention of the workshop is, at least, to open debatesaddressing the new frontiers of construction management.

WORKSHOP TOPICS

In the first planning phase of the workshop, the following topics were selected based on the collaboration of the research group of Building production at the Department of Architecture (University of Bologna) and the Construction Management and Economicsunit(Tampere University of Technology). The topics present various dimensions of interests that are seeing as potential sources for innovations and amendments to construction management, or, even to reshape it.

1. **Industry 4.0**: IoT and perspectives for the creation of Smart Factory in the construction sector.
   - Internet-Of-Things in the construction site
   - Smart Factory & value chain in the construction sector
   - Artificial intelligence and process simulation

2. **Project Management & Lean Construction**: innovative technologies and Lean Construction with the aim of time, cost, quality and safety in construction.
   - Project control for construction
   - Lean construction & process management
   - Time, cost, quality & scope management in construction projects
   - Hazard evaluation and safety management

3. **Building Information Modelling& Built Heritage**: BIM for new building construction and for renovation and conservation projectsHeritage BIM - HBIM.
   - Building Information Models
   - Building Information Modelling and construction process digitization
   - Heritage Building Information Modelling
   - Building Information Modelling and virtual reality in construction

4. **Low – impact building site design** for deep renovation building projects and urban regeneration construction projects.
   - Construction deep renovation projects for buildings
   - Low-impact construction site design
   - Urban and building-blocks regeneration projects

5. **Facility Management & Life Cycle Planning**
   - Life Cycle Assessment LCA
   - Life Cycle Cost Assessment
   - Facility management
   - Building Maintenance & operations

6. **Quality and Safety** in Project

Procurement and Project Control
- Quality management
- Safety management
- Project procurement
- Project & Process Controls

7. **Construction site design and Off-site construction**
   - Construction site design and logistics
   - Lean design of construction process
   - Off-site construction
   - Construction site safety and organization

8. **Project Management**: standards and competences in the construction sector.
   - Project Management for Construction
   - Construction management and standards
   - Real estate development and construction economics

WORKSHOP PROGRAMME

The main workshop programme included 21 presentations based on the accepted papers. Those address research results or on-going research activities that are clearly contributing new findings and knowledge with respect of the workshop main themes. Work by different scholars can be directly, partially or indirectly linked to the workshop topics listed earlier. The indirect link can mean causality or influence that have been identified in another context (e.g. business sector) but it can have explanatory power elsewhere as well.

Besides of the paper presentation the main programme of the workshop included four keynote presentations by Prof. Angelo Ciribini (The University of Brescia, Italy) “Limits and potentiality of digitalization in the construction sector”, Prof. Chris Harty (University of reading, UK) “Using BIM and digital technologies for construction management” and Prof. John L. Heintz (TU delft, The Netherlands) “Project Management capabilities for a Disruptive Future”.A closure keynote was presented by Prof. Kalle Kähkönen (Tampere University of Technology, Finland) “Need for modern multidisciplinary research and developments to change the built environment sector”.

Furthermore, three industry presentations were given in the workshop. Those were about BIM & ICT (Paola Giordani/Teamsystem corporation, Roberto Giangualano/Harpaceas corporation), and, clustering for innovation as opportunities for the construction sector (Giulia Landriscina/Cluster Build)

WORKSHOP PROCEEDINGS

The workshop proceedings are published in the IN_BO journal. IN_BO is a scientific journal of the Department of Architecture of University of Bologna. It is an on line & open

access journal, accredited by Italian Ministry for Education, University and Research - MIUR.
The special issue of IN_BO includes all accepted papers. All papers have gone through double-blind review process where the reviewers were the members of scientific committee.

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CLOSING WORDS

The driving idea of the workshop was to have an overview of some outgoing Construction Management Research activities that have relevance to this workshop, and to facilitate discussions and analyses with researchers, practitioners and students. The aim was not to reach a goal or to set limits, but to search for major understanding of some actual and future issues of the construction sector.

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1

A Spatio-Temporal Perspective to Knowledge Management in the Construction Sector

KEYWORDS: Knowledge, Knowledge Management, Heuristic decision theory, Cultural historical activity theory, SECI model

The construction sector is an informative intensive one. In every project, during each phase are generated hands-on experiences, problem solving capabilities, understanding of various means and methods, and highly contextualised solutions. This knowledge represents one of the most important assets for AECO firms. In the construction process, the development of a project requires the aggregation of several stakeholders. Many times this group of stakeholders collaborate for the development of the project and once it is delivered they disband moving on to the next project. Hence, the knowledge generated during the process by a whole of stakeholders is disrupted at the end of the project. Furthermore, the experiences gained in the process are rarely, if at all documented with the consequence that knowledge remains stored in the minds of those who were directly involved.

This paper proposes a novel interpretation of the classical theories of knowledge management considering the peculiarities of the construction sector. Starting from the study proposed by Nonaka and Takeuchi and in particular the hypertext organisation schema and the SECI model, the article proposes a redesign of the schema to allow its introduction in the construction sector. This main topic is integrated with considerations derived from the cultural historical activity theory and the heuristic decision theory that represent fundamental areas of study to integrate the general model with the means to analyse distributed and decentred organisations, and the intrinsic psychological aspects involved in the management of knowledge.

Hence, the paper proposes an integrated vision of the hypertext organisation schema studied in the construction sector. Furthermore, starting from the latter, the research proposes an interpretation of the knowledge generation and consumption process in the construction sector introducing a spatio-temporal perspective that highlights the distribution of knowledge related processesin terms of both space and time during the construction process.

INTRODUCTION

The construction sector is an informative intensive one (Dave and Koskela, 2009). In every project, during each phase are generated hands-on experiences, problem solving capabilities, understanding of various means and methods, and highly contextualised solutions (Lin et al., 2005). This knowledge represents one of the most important assets for architecture, engineering, construction, and operations (AECO) firms (Deshpande, Azhar, Amireddy, 2014). In the construction process, the development of a project requires the aggregation of several stakeholders. Many times this group of stakeholders collaborate for the development of the project and once it is delivered they disband moving on to the next project. Hence, the knowledge generated during the process by a whole of stakeholders is disrupted at the end of the project. Furthermore, the experiences gained in the process are rarely, if at all documented with the consequence that knowledge remains stored in the minds of those who were directly involved (Kazi and Koivuniemi, 2006:65-79).

Because of the recognised importance of knowledge, there is a vast literature related to the concept of knowledge management (KM). KM can be defined as *"a process of acquiring, creating, sharing, utilizing and storing intellectual assets and other stimuli from the internal and external business environment that facilitates an organization to perform successfully"* (Kululanga, McCaffer, 2001). Focusing on the construction sector, e.g. Kamara, Anumba and Carrillo (2002) proposed a framework to select knowledge management strategies. Robinson et al. (2006) presented a maturity roadmap for the implementation of KM strategies. Patel et al. (2000) investigated how Information Technology (IT) can assist KM in the context of the construction sector. Kanapeckiene et al. (2010) described an integrated model for KM in construction projects including the discussion of knowledge based decision support systems. Moreover, Rezgui, Hopfe and Vorakulpipat (2010) proposed an evolutionary perspective on KM. However, the understanding of the complex interrelations generated during knowledge and learning processes in the construction sector is still an area of open discussion.

This paper proposes a novel interpretation of the classical theories of knowledge management considering the peculiarities of the construction sector. Starting from the study presented by Nonaka and Takeuchi (1995) and in particular the hypertext organisation schema and the SECI model, the article proposes a redesign of the schema to allow its introduction in the construction sector. Due to the limitation of the hypertext organisation schema highlighted in the literature (Bratianu, 2010; Engeström, 2001), it is developed an integrated vision based on the cultural historical activity theory. Furthermore, starting from this integrated schema, the research proposes an interpretation of the knowledge generation and consumption process in the construction sector dealing with the spatial and temporal distribution of the process. Hence, it is introduced a spatio-temporal perspective that highlights the distribution of knowledge related processes in terms of both space and time during the construction process.

The rest of the paper is organised as follows. The first chapter introduces the hypertext organisation schema and proposes a first expansion of the schema to represent the typical fragmented environment of the construction sector. Starting from the limitations highlighted in the first analysis, the second chapter introduces the concept of cultural historical activity theory (CHAT) and proposes an integrated vision of the hypertext organisation schema. The third chapter proposes a spatio-temporal perspective on knowledge creation and use in construction sector. Finally, the fourth chapter contains the conclusions of the work.

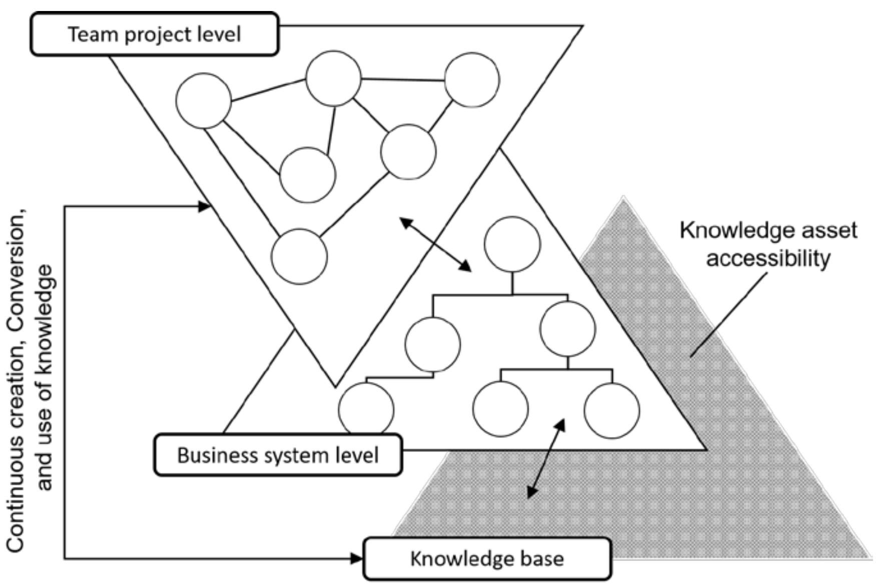

Figure 1: The hypertext organisation schema (Nonaka and Takeuchi. 1995)

KNOWLEDGE IN ORGANISATIONS

“*Sooner or later, every organization ends up creating knowledge*” (Nonaka, Takeuchi, 1995). However, the identification of where the knowledge is created, how to extract, store, share and update this knowledge, who are the subjects involved, why do they learn, what do they learn, and how do they learn represent critical questions associated to the specific environment where the learning process is introduced (Engeström, 2001). According to Nonaka and Takeuchi (1995), the knowledge creation process needs to follow a virtuous spiral moving back and forth between different mechanisms of knowledge conversion. The middle-up-down approach that they proposed highlights the importance of a knowledge conversion layer between field operators, designers and top managers. In fact, each one of these subjects has a different perception of the work and consequently a different knowledge construction in his or her mind. Moreover, each subject acts in a completely different environment (i.e. contexts) that can influence the knowledge perception (Tversky, Kahneman, 1973; Fantino, Stolarz-Fantino, 2005). Figure 1 shows the “*hypertext organisation schema*” where the continuous conversion of knowledge between different levels of an organisation is highlighted. This schema represents a fundamental paradigm in the study of organisational knowledge dynamics. Moreover, the literature is rich of studies devoted to its analysis and integration making it an ideal candidate to promote the discussion in the research community.
The knowledge base layer represents the place where the knowledge can reside and where it can be categorised and contextualised into a more meaningful product for the organisation as a whole. The individuals acting in the team project level can acquire and interpret the knowledge derived from the business system level in a complete different manner in comparison to the individuals acting on this last level. In the same way, the knowledge created in the project level is interpreted in a different context at the business system level acquiring a different value. The mobility of the knowledge and its management in the knowledge base area allows the activation of a virtuous circle of knowledge conversion allowing the creation of organisational knowledge valuable for the whole organisation.
Nevertheless, the understanding of how knowledge can be converted from one subject to another and/or from one form to another represents a crucial point. The most popular model in terms of knowledge conversion (i.e. how subjects learn) is the SECI model (Nonaka, Takeuchi, 1995; Nonaka, Toyama, Byosière, 2001; Skyrme, Amidon, 1997). It outlines four mechanisms of knowledge conversion and/or transfer:

- Socialisation: tacit-tacit
- Externalisation: tacit-explicit
- Combination: explicit-explicit
- Internalisation: explicit-tacit

Socialisation is based on direct interaction between individuals that share their experiences simultaneously, usually with analogical and practical means.
Externalisation requires the identification of means for the “translation” of experiences in a codifiable way to allow future uses. The conversion realised in a socialisation process is different from the one obtained through an externalisation-internalisation process because there is a change in time and context of knowledge usage. In fact, when tacit knowledge is shared, it still requires to be decoded by individuals (Bolisani, Scarso, 1999:209-17) and this passage is constrained by the context of interpretation.
In combination, individuals share and combine knowledge through different means including documents, meetings, and computer networks. The reconfiguration of information sorting, adding, combining and categorising explicit knowledge can produce new forms of knowledge. However, highlighting the human factor in the knowledge conversion process, Roos et al. (1998) stated that combination mechanism cannot really exist, because in this form it is a simple transfer of data and/or information without a real involvement of knowledge. For admit this mechanism, an explicit-tacit-explicit mechanism is required.

Internalisation implies the conversion of the experiences gained through socialisation, externalisation and combination in shared mental models or technical know-how for an individual. The explicit to tacit knowledge conversion is facilitated when the former can be re-experienced e.g. using

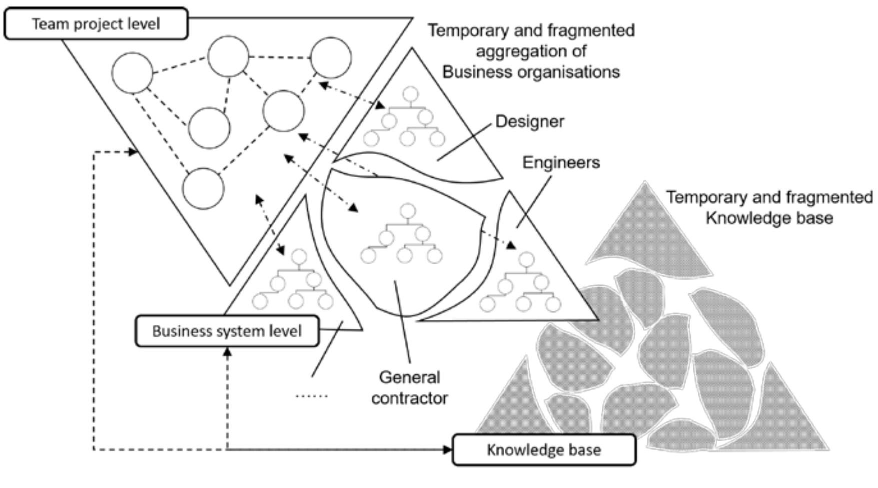

Figure 2: A simplified vision of the hypertext organisation schema for the construction sector

documents, graphical representations, or stories.

Knowledge in the Organisations of the Construction Sector

Unfortunately, in the construction sector the above-mentioned principles cannot be directly applied. The temporary aggregation between clients, designers, construction companies, field operators and the other stakeholders makes difficult the identification of the effective hierarchical roles and consequently the definition of structured KM processes. Furthermore, the conversion processes, that represent the learning activity, needto be managed in a cross organisational context. This is a critical point due to the unwillingness of the stakeholders in sharing information with other partners that are seen as competitor entities.

Figure 2 shows a possible simplified reinterpretation of the hypertext organisation schema proposed by Nonaka and Takeuchi. In this representation, the business system level is disrupted to admit the identification of the different stakeholders involved in the development of a project, each one with its own hierarchical and organisational structure. The knowledge base level is in turn disrupted representing both the knowledge embedded and generated by each subject at the business system level and the knowledge generated by the subjects as a whole at the team project level highlighting its volatility in this framework. Moreover, the coexistence of a temporary aggregation, i.e. the team project that impose defined and specific norms and rules, and of companies that can have long histories and defined processes and hierarchies can generate points of friction and consequently difficulties in the creation of an ideal learning environment.

SOCIETAL AND CONFLICTING ASPECTS: AN ACTIVITY THEORY PERSPECTIVE

As pointed out by Engeström (2001), the knowledge conversion model proposed by Nonaka and Takeuchi assumes that the assignments for knowledge creation are given from above without conflicts. Hence, the SECI model requires the creation of a friendly environment (i.e. the creation of "*sympathised knowledge*") where knowledge and learning processes are defined in a top-down approach (Engeström, Miettinen, Punamäki, 1999). This assumption is in contrast with the typical project environment in construction processes. Moreover, Bratianu (2010) critically analysed the model highlighting its limitations according to the cultural context of application. Hence, the proposed schema needs to be expanded in order to understand the societal and interpersonal relations in a distributed, conflicting and fragmented environment.

Cultural Historical Activity Theory

As proposed in other studies (Hartmann, Bresnen, 2011; Miettinen et al. 2012), cultural historical activity theory (CHAT) can be used to explicit the complex of relations and factors that rise in a construction project environment. CHAT was introduced between 1920s and 1930s by Vygotsky (Bratianu, 2010) that formed the concept of *cultural mediation*. According to Engeström and Escalante (1996), from the Vygotsky's principle CHAT has evolved through three generations of research. The first generation, centred on the cultural mediation idea, is commonly represented through a triangle of interaction where the connection between subject ("stimulus" in the original representation) and object (or response) is mediated by cultural artefacts (Figure 3, left). According to this schema, individuals and society cannot be understood without their mutual interaction and cultural means. The second generation, based on the work of Leont'ev (1978), extended the first model explicating the difference between individual action and collective activity. This concept was crystallised by Engeström (1987) that proposed the graphical representation reported in Figure 3 on the right. In this expanded

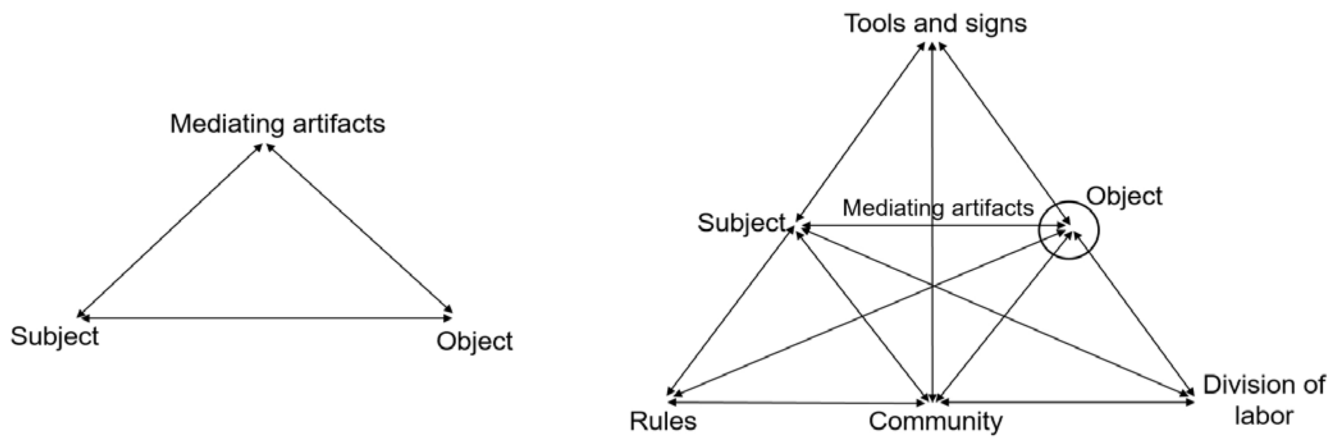

Figure 3: Reformulation of Vygotsky's model (left), and the Engeström's graphic representation of a human activity system (right)

framework, an individual subject is immersed in a complex of interrelations centred on his or her community creating a human activity structure.
The third generation of CHAT deals with the interaction between different activity-systems that can include different traditions and/or perspectives. Figure 4reports the graphical representation of two interacting activity systems proposed by Engeström (2001), highlighting the movement, the evolution and the different perspectives of the object in the interaction between the two activity systems. In the Engeström words, "*the object of activity is a moving target, not reducible to conscious short-term goals*".
Figure 4 represents a minimal model of interacting activity system. Nevertheless, it can be expanded to represent the structure of an articulated project that can include several activity systems.

Hypertext Schema and Activity Theory in the Construction Sector

Integrating the paradigm of interacting activity systems in the reviewed structure proposed in Figure 2, it is possible to define an integrated vision of the hypertext organisation schema for the construction sector (Figure 5). At the business system level, each triangle represents a specific entity (e.g. a company) that participate to the development of the project. The business system level highlights the independencies of each entity in its subjectivity and its interrelation by means of the project terms and objectives. At the team project level, each part of the entities identified at the business system level can be represented as an activity system that collaborate on a shared object (e.g. a building). According to the CHAT principles and following a recent interpretation in the construction sector proposed by Miettinen et al. (2012), the object is interpreted by each subject in a different way according to the specific interest and background of this last. Moreover, the norms and rules that regulate each activity system at the team project level are generated by the integration of the direction defined at the business system level and the directions imposed by the external environment where the construction project is embedded.
This interpretation highlights the complexity of interaction and the interpretation of the knowledge generated during the project activities. In fact, the coexistence of different communities and perspectives shape the way in which subjects act at the project level and the way in which they interpret and convert the generated knowledge.

When and Where Knowledge is Created and Used? A Spatio-Temporal Perspective

While the framework proposed in Figure 5 can help in understanding the organisational structure in construction projects and the interactions between subjects, it is not able to capture the spatial and temporal distribution that characterise the construction process. Hence, it can be integrated with a spatio-temporal perspective able to express these dimensions. Analyse the spatial and time distribution of knowledge represents a critical point to understand its management and transfer processes. In fact, while knowledge moves from one place to another and while it moves forward in the time, its perception change due to the change in the context and in the availability of the surrounding information.

Figure 6 reports a qualitative representation of the impact in the production and use of knowledge during time in the different locations involved in the construction process. The graph has been empirically defined combining the evidences found in the literature and the observations of real construction processes. The proposed representation includes three locations, namely construction site (i.e. the place where the construction product is produced),

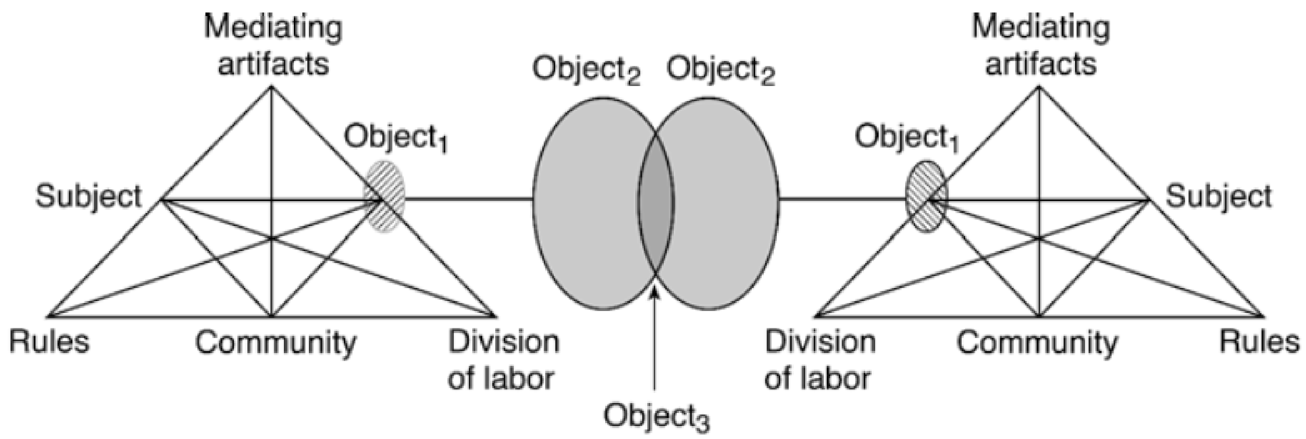

Figure 4: Representation of two interactive activity systems (Engeström, 2001)

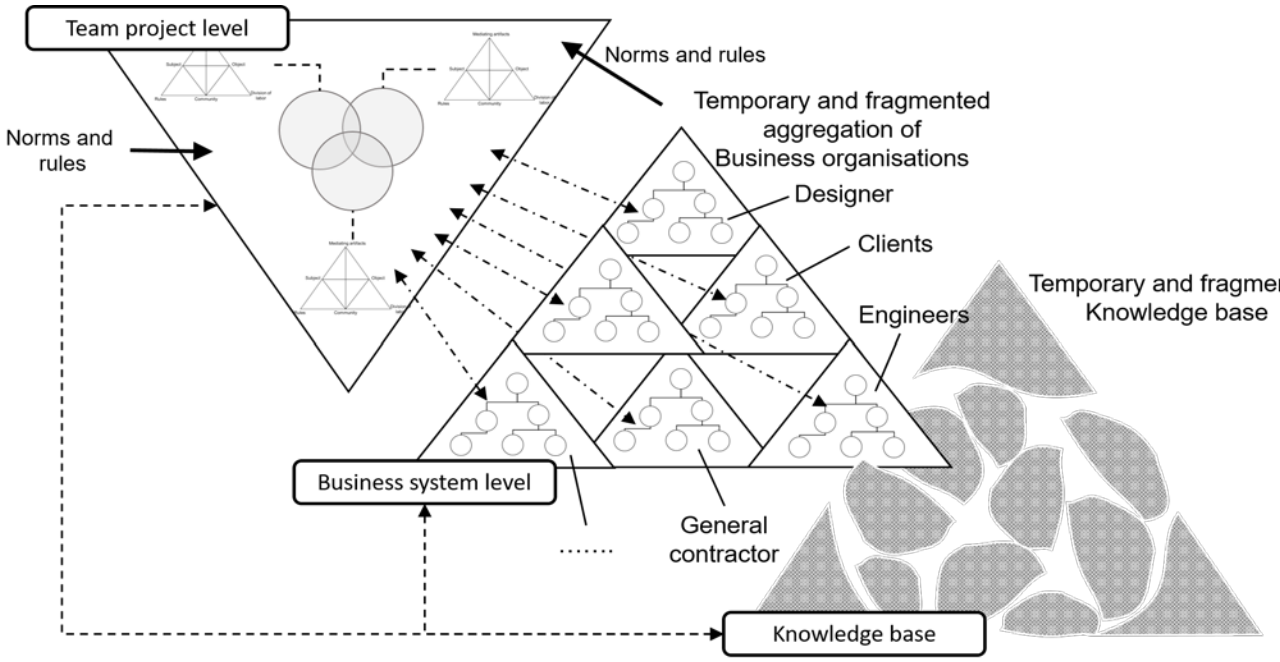

Figure 5: An integrated vision of the hypertext organisation schema for the construction sector

product (i.e. the construction product such as the building or the infrastructure, once it is completed), and offices or factories (i.e. the places external to the physical location of the product where this last is designed and monitored and its components are designed, produced and monitored). The horizontal axis indicates the time correspondent to the three main phases of the construction process, namely design, construction, and operation and maintenance. The vertical axis reports the impact in terms of knowledge production and consumption, defined in qualitative fashion. According to the literature (Lin et al., 2006) in the construction phase, and especially in the construction site, there is an intensive production of knowledge as a consequence of the concentration of efforts devoted to the production of the good. Towards the end of the production, the construction site is progressively transformed in the product that will produce knowledge during its entire life cycle. Hence, the impact of construction site decrease while starts the impact of the product as a physical place. In the proposed representation, the time scale is not coherent to the real life cycle of the building due to scale problem. In fact, operation and maintenance phase can be seen as longer than it is in the graph. The oscillation of the graph in the operation and maintenance phase highlights the dynamicity of the impact along the life cycle that can change according to specific events including maintenance, and/or restoration.

In every phase and in every location can be recognised examples of both tacit and explicit knowledge. The design phase is characterised by an intensive use of regulations (e.g. national, local, hygiene), standards (e.g. fire safety, acoustic, management), and other requirements (e.g. clients requirements). Many of the solutions that can be used to fulfil these requirements can be converted in an explicit form of knowledge and can be stored and used through digital tools. For example, several studies explored the use of IT solutions to handle this explicit dimension. These include the use in energy simulations (Cheng, Das, 2014), the use of ontology-based approaches (Yurchyshyna, Zarli, 2009; Zhong et al., 2012), the evaluation of permissions from public administrations (Pavan et al., 2017), and the representation of regulatory knowledge through open standards (Dimyadi, Pauwels, Amor, 2016). Nevertheless, the identification of the correct solution between all the possible ones that can be proposed by an algorithm, the interpretation of design solutions in their context in a human perspective and the management of design teams are only some examples of the variety of tacit knowledge that can be experienced in the design phase.

During the construction phase, the stakeholders mature genuine experiences about the constructability of a specific solution, the effective applicability of the solution in the context and its alignment with time and costs hypothesized in the design phase. Hence, during the construction phase are generated problem solving, know-how, know-what and innovation (Lin, Wang, Tserng, 2006). In this phase mostly of the knowledge is tacit and its collection and transmission is a critical issue in the process. In fact, in a general contractor environment, the site work is subcontracted to various trade contractors on a competitive tendering basis. Therefore suppliers have no incentive to share learning experiences (should read knowledge) for the sake of reapplying them on future projects of the main contractor (Koskela, Vrijhoef, 2001). Furthermore, in the construction phase the interaction between designers, engineers, clients, authorities, contractor, and subcontractors produce a dynamic environment of knowledge generation and conversion. However, there is not a unique business level where can be established techniques and technologies to document this knowledge asset.

The operation and maintenance is distributed in a long time span. Furthermore, once the design and construction phase is concluded, it is difficult identifying who is the subject interested in the collection, management, use and update of the information and of the experiences produced during the life cycle of the construction product. In other sectors, like the automotive one, the manufacturer can act as central collector in all phases including design, construction and monitor of the product. In the construction sector, this is hardly the case. Nevertheless, there is a substantial learning opportunity from the analysis of a construction product (i.e. building, infrastructure) during its operation. For example, the durability of a technological solution can be assessed along its life cycle, and the effectiveness of a design solution in satisfy the client's requirements can only be evaluated following the experiences of the client.

CONCLUSIONS

This paper proposes a critical analysis of the hypertext organisational schema and of the SECI model presented by Nonaka and Takeuchi to evaluate their possible integration in the construction sector. The above-mentioned paradigm presents several issues when introduced in a fragmented and conflictual organisational environment. In particular, the difficulties in creating a friendly environment and the temporal aggregation of subjects with a different cultural basis can hinder the principles of the hypertext organisational schema and of the SECI model. Hence, considering the peculiarities of the construction sector and the complex of interrelations between the possible stakeholders involved in a project, the author of this paper proposes an integrated interpretation of the hypertext organisational schema including the societal and cultural aspects derived from CHAT.

The author argues that a spatio-temporal perspective must accompany an organisational vision on knowledge because of the spatial distribution of construction sector's products (buildings, infrastructures) and the long life cycle of these last. Hence, the author proposes a qualitative graph that can represent the evolution of knowledge creation and consumption during the construction process.

Nowadays the study of collaborative means and environments supported by digital processes and instruments represents one main area in the research field. Several studies proposed frameworks and solutions related to both collaborative and KM environments. The proposed schema can help in further developing the existing frameworks starting from a theoretical comprehension of the relations between the involved stakeholders to optimise their processes of use in the practice. Hence, future research can look in the development of collaborative environments and/or KM environments frameworks based on the proposed schema answering questions such as how can we optimise the integration of new processes e.g. based on digital means in the construction sector?. Moreover, a quantitative evaluation related to the proposed spatio-temporal schema can be identified as a valuable future line of research.

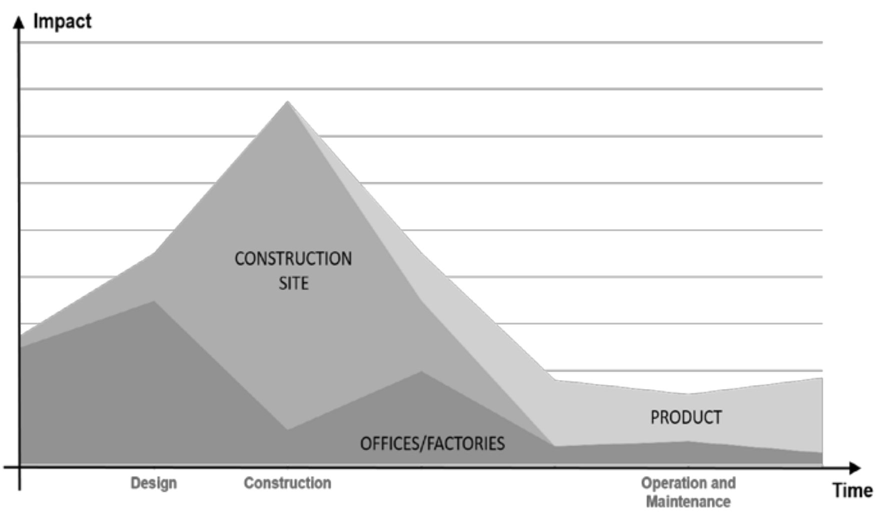

Figure 6: A spatio-temporal perspective in knowledge generation and use

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2

Cost-Oriented Tool for Life Cycle Planning

KEYWORDS: Maintenance, Management, BIM, LCC

The Industry 4.0 opens to the sector of building constructions a new perspective, especially in relation to the digitalization of information and to the use of Big Data Analytics to manage them. Gathering data on new and existing buildings to provide a more and more complete view on the outcomes of the choices of construction, in order to ideally optimize the designing process, has already been identified as one of the main purposes. Yet, despite the available data are much less, the same vision can also make it possible, by enhancing and emphasizing monitoring activity in this field, to build another kind of database, involving an aspect that is equally crucial for a building and its components: the building management phase, that is to say the planning of maintenance activities, the cost of which cannot be overlooked. Looking ahead to the possibility of developing such database, multiple ways of making use of it to guide designers in the choices related to life cycle planning, unfold. Considering a necessary step that of realizing tools to evaluate such choices according to at least one parameter, in order to guide designers towards choices that are consistent with their purposes, this work investigates the possibilities in this field, and proposes a software tool to elaborate strategies and compare them on the basis of the cost parameter. Finally, hypothesis of inclusion of this kind of software in a BIM platform are suggested, in a view of facility management of BIM 7D.

INTRODUCTION AND STATE OF THE ART

Every year, the building sector is interested by significant cash flows: building works are one of the most 'expensive' items in the market, and Italy in particular is suffering from a significant decrease in the number of new constructions, a phenomenon which can be attributed to many reasons of various nature, among which financial ones. Consequently, in the analysis of building operations, interventions on existing buildings are becoming more and more relevant in comparison to new constructions, following a trend which had already shown several signals in the last decades.

It must also be pointed out that, for a building, initial costs of construction only represent a small part of the global cost, while management costs, which include maintenance as well, constitute a much more relevant share.So, together with the less and less consistent presence of new constructions in the Italian building market, it seems correct to state that, in order to reduce the cost of the building sector, intervening on the costs of maintenance is an important and necessary focus.

Too often, designers thought that there was always an economic benefit in intervening on a component to restore its performance instead of substituting it.Following this purpose, muchresearch has been carried out in the field of restoring interventions, but actually, at least from an economic point of view,the evaluation on whether it is convenient or not, depends from the service life of the component, the cost of substitution, and the cost of the restoring intervention considered.

This reasoning can be applied to any maintenance intervention, and by extension to a maintenance strategy: what is the global cost of the maintenance that is executed on a component? Then, how much do these interventions lengthen its life? Is it a choice that realizes the higher economic benefit? Asking these questions has actually a standard since a relatively long time ago in the industrial field, in which the consequences related to the increase of performance can be directly seen in terms of productivity. In fact, Preinreich (1940) elaborated a model for the determination of the economic benefit deriving from equipment maintenance quite early; then, Eilon, King and Hutchinson (1966) studied the same subject focusing on the trucks. Christer and Goodbody (1980) applied their models in order to find the limits of convenience, and some years later proposed an application on medical equipment (Christer and Scarf, 1994). Their approach consisted in setting the periods between interventions and the costs of interventions as variables, then finding the values that maximise and minimise the functions related to economic incomes.

One of the first applications to buildings is that of Blazenko and Pavlov(2003), specifically concerning real estate investments: in this work, the net values of maintained and unmaintained investments are defined and compared, making use of the concept of risk to compute the negative consequences deriving from poor maintenance. Later, Harding, Rosenthal and Sirmans (2007) identified maintenance as a non-negligible factor of cost depreciation, and suggested a model in which the maintenance activity that is executed is parametrized through its cost over time. In the listed models, though, especially the ones on real estates, the issue of different typologies of maintenance activities and interventions is not fully taken into account. This makes it less realistic, as even with the same costs, different maintenance strategies can lead to different effects on components and buildings. Manganelli (2013) indeed emphasizes the close relationship between maintenance and building depreciation, recognizing at the same time the difficulty to quantify it. The variation of the economic value of a building could in fact constitute a reliable parameter to compare maintenance choices according to cost, as Del Giudice et al. (2016) suggest, in particular in relation to the cost depreciation method.

Unfortunately,itmustalsobesaidthatthe main difficulty in modelling the relation between maintenance and economic value in a building, is also caused by the issuesin predicting with precision the effects that maintenance has on the components. In fact, there is some uncertainty on determining the service life of a building component even in absence of maintenance interventions, as several factors, including climate, position on the building, constructive features, affect this characteristic. Moreover, experience shows that the effect of a maintenance intervention on a component can change deeply according to the moment of its life at which it is executed. So, evaluating this variation might apparently seem an unreachable goal.

Thankfully, there are two more elements to consider. For example, Gottfried (1992), by making use of statistical analyses, approximations and evaluations, estimated the mean values of service life for several building components, in presence or in absence of maintenance interventions. Some theorists of the cost depreciation method, for example, use them as reference values for its application. This set of data could not be used directly to evaluate the most convenient maintenance activity, as it was obtained considering a bi-stable logic – with or without maintenance – so the matter of choosing among different possibilities of maintenance scenarios is not taken into consideration at all. Yet, this approach provides the suggestion to obtain similar values by carrying out statistical analyses on different degrees of maintenance, rather than on these two opposite scenarios.

The other element is constituted by an encouraging research carried out by Serrat et al. (2017), constituted by the monitoring of a high number of buildings in the city of Barcelona, in order to evaluate and measure the performance of their components over time, on which maintenance interventions are executed. The purpose is that of

obtaining performance-time curves that define the behaviour of components, and mathematical models that describe the effect of the various maintenance interventions on those components.
Looking forward to the realisation of these purposes, and to the possibility to adapt the results to other contexts by using tools such as the Factor Method or by comparing the results to those of hypothetical future similar experimentations, it seems that this kind of work may be a good path to gather reliable information on the parameters needed to perform economic evaluations on maintenance choices. This paper will explore the process to perform this kind of evaluation and analyse which kinds of software could be good for its actuation.

ECONOMIC CONVENIENCE OF MAINTENANCE STRATEGIES

Components

For a given component A, the number of years of which its spontaneous duration, that is to say service life in absence of maintenance interventions, consists, can be named v_A. Then, during its life, the component can be subjected to ndifferent types of maintenance interventions I_{Aj} (I_{A1}, I_{A2}, I_{A3}, …,I_{An}). Each of the interventions is characterized by a cost C_{Aj} (C_{A1},C_{A2},C_{A3},…,C_{An}) and by an increasing effect on the residual (and then, the total) service life of the component. The amount of this increase changes according to the time of execution of the intervention, with a tendency that depends on the typology of the intervention and of the element. For example, tendentially a layer of paint applied on a plaster covering remains in a good state for about 5 years, then starts showing signs of decay, until the point, at around 10 years, when there is a drastic decrease in the protection it offers to the plaster. Considering the direct relation between the protection that paint offers to the covering and the duration of the latter, a painting intervention produces a more significant increase in the service life of the plaster covering if it is executed after 10 years, than after 5 years or less. Moreover, this connection with time is not only in relation to the year of construction, but also to the interventions that have already been performed on the element. Also, this reasoning cannot be applied in the same way to ameliorative maintenance, as it is not true that carrying it out shortly after the beginning of service life produces little increases in it. So, since these laws of variations may change in every case, and none has ever been modelled for any intervention nor for any component, it is necessary to avoid making it explicit in the description of this evaluation. It is possible to introduce a proxy parameter which takes into account all the interventions that have been executed before a given time t_i, named Maintenance History before the time $t_i$or MH(t_i). So, the increase of service life related to the execution of a maintenance intervention I_{Aj} on a component A at a time t_i can be expressed as $\Delta v_{Aj} = f_{Aj}(t_i, MH(t_i))$. It must be said, though, that a simplified solution could also be represented by the use of a stochastic function.
So, considering a maintenance strategy α_k on the component A, and the homonymous set of the interventions that are executed on it in that strategy, then the total service life of the component in this maintenance strategy is calculated as:

$$v_{\alpha k} = v_A + \sum_j \Delta v_{Aj}\, , j \in \alpha_k$$

$v_{\alpha k}$: service life of component A in strategy α_k;
v_A: spontaneous duration of component A;
Δv_{Aj}: service life increase related to the j-th maintenance intervention of strategy α_k.

In order to evaluate the economic benefit deriving from the extension of service life to v_A to $v_{\alpha k}$, it is possible to make use of a model recently suggested for the evaluation of the convenience of restoring interventions by comparing the increase of service life and the cost of the intervention by calculating the economic value related to the employment of a component for n years, named Component Employment or CE(n). It can be calculated as:

$$\mathrm{CE(n)} = \mathrm{A_v} \cdot \frac{1-(1+\mathrm{i})^{-\mathrm{n}}}{\mathrm{i}}$$

CE(n): Component Employment for n years;
A_v: annual value of a series of constant annuities, obtained from the equation below;
i: interest rate;
n: duration of service life.

A_v is obtained from the following equation, which equals the initial cost of construction of a component, reduced by the back-discounted residual value at the end of service life, if present, and the expression of v constant annuities, which correspond to the v_A years of the spontaneous duration of a component A:

$$C_0 - V_r \cdot (1+i)^{-v} = A_v \cdot \frac{1-(1+i)^{-v}}{i}$$

C_0: cost of construction of the component;
V_r: residual value of the component at the end of the service life;
i: interest rate;
v: spontaneous duration of the component;
A_v: annual value of the substitutive series of constant annuities, unknown term of the equation.
So, if the service life of the component A is increased to n years through a

maintenance strategy α_k, then it results that CE(n)>CE(v), and the difference between the two is indeed the economic benefit deriving from execution of the maintenance strategy α_k on that component.
Of course, the cost of the strategy α_k on the component A corresponds to the summation of the back-discounted costs of the interventions executed over time, indicated as Maintenance Cost or MC(α_k). By reducing this value by an amount that is equal to the difference between CE(n) and CE(v), the effective cost of the maintenance strategy is obtained, and this, named MC*(α_k), represents the parameter on which the evaluations on the economic convenience of the strategies can be based.

WHOLE BUILDING

As when evaluating the economic convenience for a single component, for the whole building as well the reference parameter is constituted by the lowest effective cost MC*¬. Yet, components are not mutually independent parts of a building, but rather two types of connections have been identified by Nicolella (2003):

- technological connections, those where two elements are bound to each other, so that it is necessary to intervene on both at the same time. For example, plaster and paint have a strong technological connection: when intervening on plaster, paint is affected by the intervention too, and so an intervention has to be performed on it as well;
- operative connections, related to the convenience to associate interventions on two elements, because of reasons of executional nature, such as equipment, provisional works, work yard organization. For example, the entity of the installation cost of scaffolding makes it particularly opportune to carry out at the same time works on all the components that require its employment: plaster and paint of vertical enclosures, cornices and balconies with all their components, coverings, downpipes, gutters, etc.

This means that, while two strategies on two different components could respectively be the most convenient for those components, their combination could produce a lower benefit than another set of two strategies, as they might not too compatible, considering the connections that exist between the two components.So, their influence on the global convenience can be noticed only in the combination of the different maintenance strategies on the single components. Heuristically, this could be solved by applying small adjustments to the times of intervention of the

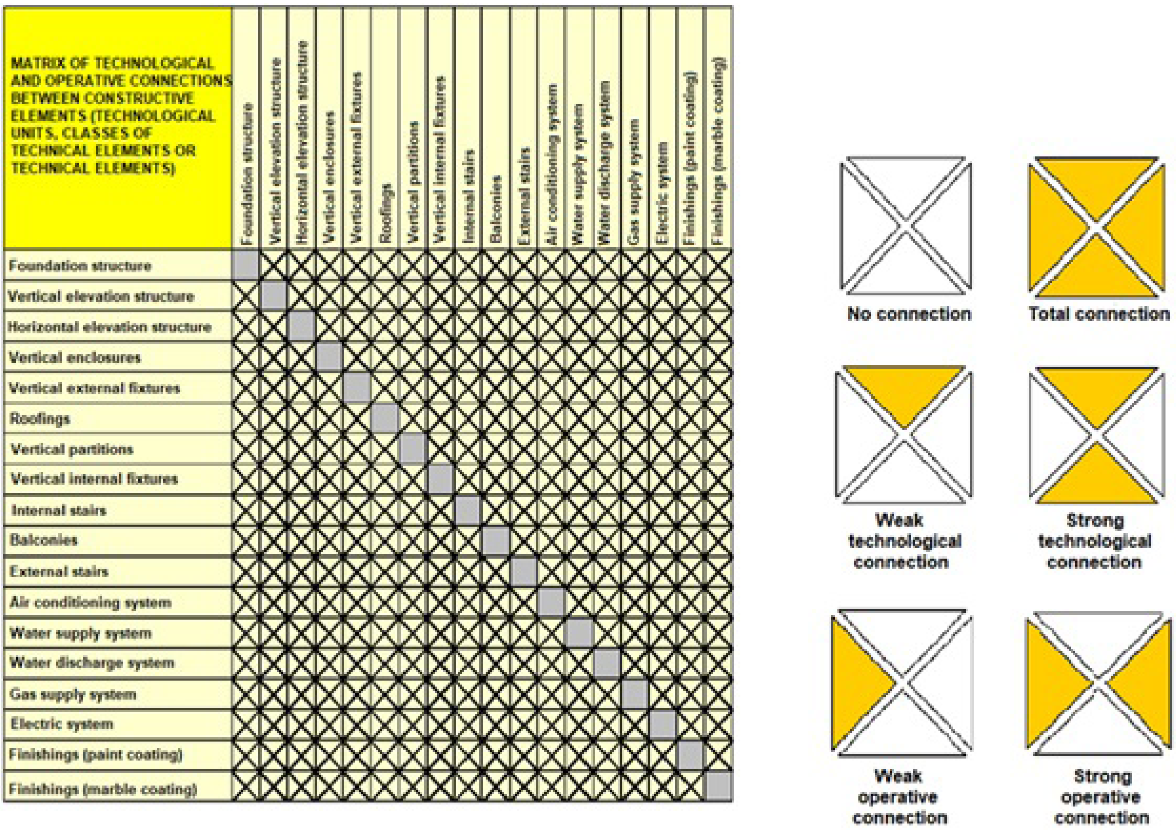

Figure 1: Blank pattern of connections matrix and connection symbols legend

single maintenance strategies on the components that have shown to be respectively the most convenient; of course, this process is on one hand easily applicable, but on the other hand hides other combinations which may have higher synergies.

SOFTWARE-BASED EVALUATION

As it has been shown, technological and operative connections make it necessary to consider the combination of the maintenance strategies on the whole building together, rather than ranking the convenience on the single components separately, to reach the conclusion of which choices lead to the most proficient result, in economic terms. It is evident, though, that the approach of evaluating all the combinations, even if a selection were applied to the total number of combinations, is a task which could hardly be performed manually. So, it was chosen to experiment hypothesizing and developing a software which could run this process automatically, by:

- generating all the possibilities for maintenance activity on each of the components for a chosen period of time, drawing information on the interventions from a database;
- calculating, within a range, the resulting service life for each strategy;
- combining the single strategies on different components to generate maintenance scenarios for the whole building;
- evaluating MC and MC* for the single components and for the whole building;
- ranking the maintenance scenarios.

The software, which is currently in development,is structuredthrough an offline client/server model, with a Java client and a PostgreSQL database server. The database schema contains the interventions, and has a relation for each of the components, in the form: ElementA (name,code,cost,package,servlife,tools1,tools2).

The first two terms correspond, respectively, to the detailed name of the intervention, and to the short code that is used to ease the visualization of the strategies and combinations; the cost is the unitary cost of the intervention, derived from price lists; 'package' indicates the technical solution of the component on which the intervention is executed (for example, if the considered component is the vertical enclosure, masonry or plasterboard); 'tools1' and 'tools2' refer to the equipment, machinery and provisional works needed to carry out the intervention, if the costs needed to put them in use are relevant (for example, the operations of mounting and removal of a scaffolding or the use of hammers or drills); 'servlife' is the form of the function, indicated in the previous paragraph as $f_{Aj}(t_i, MH(t_i))$, which is used to determine the increase of service life of the component related to the maintenance intervention. Since the software is still in development, and a full database on the possible maintenance interventions has not been implemented yet, the current one only contains placeholders. The placeholders take the form of codes containing the initials of the category they belong to (the letter of the components for the packages, M for machineries, W for provisional works and E for equipment regarding the tools); the relationships that are used to determine the service life are currently modelled as generic basic functions.

Every relation also contains additional strings, as many as the technical solutions hypothesized for the corresponding component, which are used to simulate the lack of execution of maintenance interventions (for one year).

name	*code*	*cost*	*package*	*tools1*	*tools2*	*servlife*
Intervention 1	A-I1	5	A1	M1	-	t+4
Intervention 2	A-I2	10	A1	M1	M3	5-t
Intervention 3	A-I3	10	A1	M2	M1	t+2
Intervention 4	A-I4	15	A1	M1	E2	6
Intervention 5	A-I5	5	A2	M3	W1	2
None1	-	0	A1	-	-	0
None2	-	0	A2	-	-	0

code	*name*	*c-area*	*c-length*	*c-volume*	*c-mass*	*c-unit*
M1	Machinery 1	5	7	6	3	2
M2	Machinery 2	4	2	5	7	1
E1	Equipment 1	8	9	3	5	8
E2	Equipment 2	11	7	9	1	2
W1	Prov. work 1	4	6	8	6	6
W2	Prov. work 2	2	5	3	9	7

Table 1: Sample attributes of the relation of component A
Table 2: Sample attributes of the relation of equipment, machinery and provisional works

In the database, another relation contains the attributes related to the equipment, machinery and provisional works indicated above. In particular, the strings contain data on their unitary cost, in function of as many parameters as they are available in the price lists. Specifically, the strings are: 'code', corresponding to the code also indicated in 'tools1' and tools2; name, the extended name; 'c-area', 'c-length', 'c-mass', 'c-volume', 'c-unit', which are respectively the unitary costs which have to be multiplied by the quantitative measures of area, mass, length, volume or unit of the components to obtain the cost of the interventions.
The last relation is made up of the technical solutions, consisting in only one string whichreports spontaneous duration.
The following input data are required by the client:

- period of maintenance activity (in years);
- list of components (selectable from a list);
- technical solution of each component (selectable from specific lists);
- quantities of the components.

The specification of the technical solution is necessary to restrict the set of interventions of reference, for each component, to the ones in which the package corresponds to the chosen item. Then, the first operation run by the client is the generation of the combinations corresponding to the maintenance strategies for the single components, through a script for Combinations with Repetitions, where the size of the selection, l, corresponds to the duration of the period of maintenance activity. The computed set S is, of course, the one constituted by all the interventions automatically selected through the package parameter in the relation of the specific component. Then, given the cardinality of the set p, the total of the generated strategies is p^l. Most of these will present interventions almost in every year, so only a few of them will be relevant when evaluating the economic convenience.

For each of these sequences, MC, $v_{αk}$ and MC* are calculated. Through Java functions, the unitary cost of every intervention is multiplied, for every time it appears in the sequence, by the quantitative measure that has been specified for the component, and the single costs are summed. In the same way, a $Δv_{Jj}$ is calculated for each intervention by executing the function related to the interventions. In the current form of the software, the function only depends from t_j, as the shape of the dependency from $MH(t_j)$ has not been researched yet; then, the single increases are summed to spontaneous duration to obtain the total one. Finally, MC* is calculated as the difference between MC and the difference between $CE(v_{αk})$ and $CE(v_A)$.

The following operation is the generation of possible maintenance strategies for the whole building, by combining those obtained above. In this case, the client runs a script for Combinations of Elements of Multiple Arrays and produces all the combinations between the arrays containing the previously obtained sequences, forming an extremely high quantity of maintenance possibilities. Clearly, as stated before too, most of these combinations will have no relevance in terms of practical use. Then, MC and MC* are recalculated by the software - service life of the components does not change as it has been hypothesized that its value for one of the components is not affected by the actions on the others. When calculating the total cost of maintenance MC, technological and operative connections have to be taken into account. While technological connections are mostly present between the elements within components, and so their effect is actually visible in the evaluation of the convenience of the combinations of the single components, operative connections can be considered through the strings referring to common machinery, equipment and provisional works. The software runs, in fact, a process of correction of the total cost based on the verification of the presence of common values in the strings 'tools1' and 'tools2' of the interventions taking place in the same year on components that have an operative connection between them. Then, it calculates the cost of the tool for both components, by multiplying the unitary cost corresponding to the unit of the quantitative measure that describes each of the two and applies to the global cost a reduction corresponding to the 50% of the lower cost between the two. This appears to surrogate the economic benefit deriving from the chronological optimization of the interventions on components with operative connections.
Subsequently, MC* is calculated as before. Eventually, the software runs a Ranking Method script to show a ranking of the strategies according to this parameter.

HYPOTHESIS OF INCLUSION IN A BIM PLATFORM

Thinking of the typology of input data required by the software, it seemed appropriate to analyse its possible link to a BIM platform. The software illustrated above is actually mainly conceived as the practical verification of the possibility to build a software architecture to automatize the whole process of evaluating the economic convenience for a high number of possibilities in regard to the maintenance of a building. So, the consideration of a possible inclusion in a BIM platform does not specifically refer to this software, still in development, but to any software realized with the logic and with the purpose explained until now. For this reason, the following statements mainly stand as speculative hypotheses, rather than being related to ITissues, considering in fact the possibility to create similar computing

architectures with different systems, codes and computer languages.
In particular, the possibility to develop a plug-in feature to automatically obtain the data related to the quantities of each component by making use of the computing functions of BIM platforms, could drastically simplify the tasks of the users. The same principle applies to the definition of the technical solutions, which could be indicated in a more open way in the software, in order to draw directly information on the components of components from the BIM model; this would be subordinated, though, to the manual selection of the number and nature of the components.

CONCLUSIONS

Although national regulations have been undoubtedly pushing forward programmed maintenance, and in some local cases have deeply enhanced its implementation, objective criteria for the definition of life-cycle planning of buildings are rarely considered an item of discussion, and often the task of designing maintenance results limited to adapting pre-established patterns to the specific cases.
The purpose of exploring the theoretical process to realize an objective evaluation of different possibilities in the field of maintenance, and providing the guidelines to follow this path, was indeed conceived as an encouragement to carry out quantitative analysis on the characteristics of maintenance planning, in order to choose the most suitable solution.

It must be stated however – once more – that the project of developing such apparently quantitatively accurate software is probably an excessively anticipated aim, considering that objective data on the durability of building components are far from becoming available and comprehensive of a sufficient range of technical solutions. Despite that, developing approaches for a beneficial use of such data presumably constitutes a step forward being able to improve the techniques of designing maintenance.

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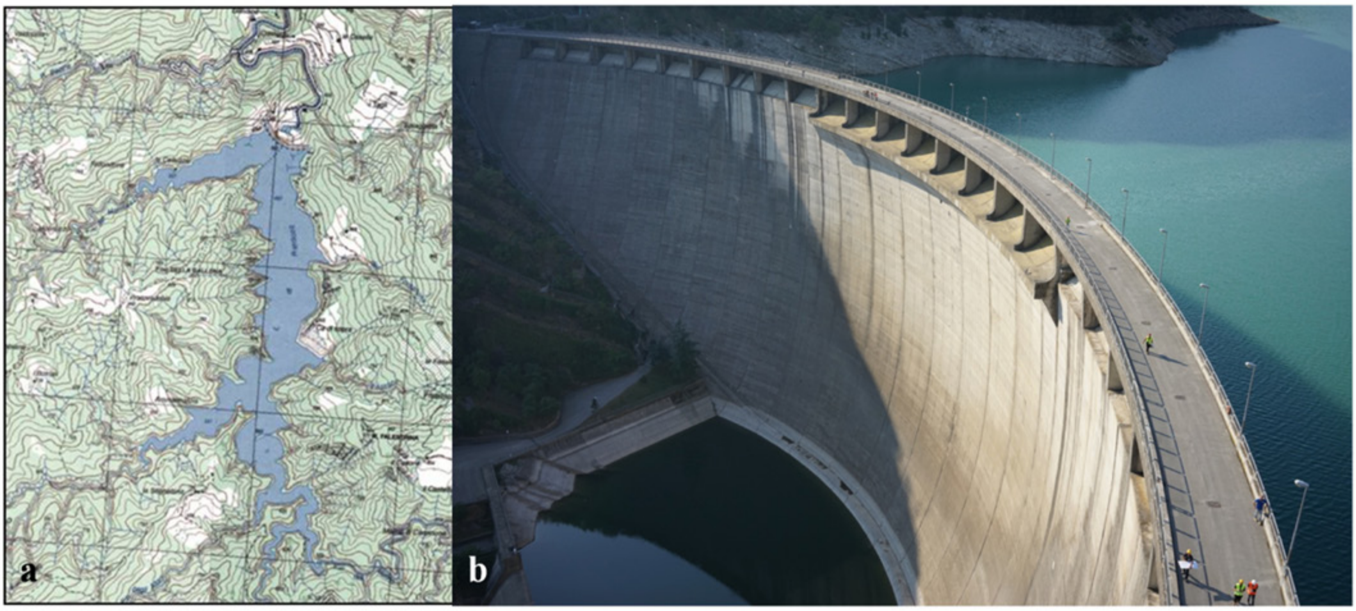
3

Unmanned Aerial Vehicle (Uav) and Building Information Modelling (Bim) Technologies in Concrete Dam Management: The Case of Ridracoli

KEYWORDS: UAV, Dams, Solid Modelling, BIM, Efficient Management

Safety and proactive vision are key aspects for an efficient management of dams. The reduced accessibility and the large time needed for an inspection by traditional methods do not facilitate their direct visual inspection. Therefore, the use of Unmanned Aerial Vehicle (UAV) is suitable for this purpose, although the support of traditional topographic instruments (i.e. Total Station, GPS Station and Laser Scanner) is still necessary. The UAV survey provides qualitative information, with the aim of recognizing the condition of the materials (i.e. photos, videos), as well as quantitative information, with the aim of modelling the structure (i.e. geo-referenced dense point cloud). Since multidisciplinary aspects are involved in the management of dams, the possibility to share data (i.e. photos, videos) of every detail of the structure, also on different times and in different places, between a large number of specialists (i.e. engineers, architects, geologists, technicians, managers) allows for the effective and efficient resolution of problems. The UAV dense point cloud, integrated also with pre-existing data sets, is the base for the extraction of surfaces which describe important elements of the structure. The solid model is employed in Finite Element Method (FEM) analyses or, including additional information concerning volumes, mechanical characteristics, monitoring data, etc., it could be able to be the basis for a Building Information Modelling (BIM) of the dam system. The aim of the present paper is to explain the products of a UAV survey of a dam useful for storing and sharing information and for developing the starting point of a BIM of the structure. Case of study is the arch-gravity dam of Ridracoli, it has been the object of a technological comparison between traditional topographic instrument and the innovative UAV technique. The photo/video database captures the reference state of the structure and allows to investigate possible damage phenomena over time, moreover, by means of photomodelling technique, it provides the dense point cloud as a basis for a BIM.



INTRODUCTION

As explained by Fornari and Marcello (2012), in Italy there are 541 large dams, with an average life of over 50 years, which may extend to 70 years if the analysis is limited to the Alps. The need to, ever more effectively, combine safety with the containment of maintenance costs directly linked to the service life of the structure requires innovative approaches beside traditional methods.

The reduced accessibility of dams does not facilitate direct visual inspection and a large amount of time is required for an inspection by traditional methods. Although a reliable terrestrial survey is still necessary, as Buffi et al. remind (2017), the use of UAVs is well suited for this purpose, as suggested by Colomina and Molina (2014) and Ellenberg et al. (2015). The use of UAVs is spreading to the safe inspection of sections of infrastructure that would otherwise not be directly accessible, except with expensive and dangerous procedures. The state of conservation of the materials can be monitored in order to guarantee a proactive maintenance of the structure, as reminded by Salvini et al. (2017). However, the use of UAV technique on dams is still rare and at an early stage, Naumann et al. (2013) published one of the first work on this topic.

As reminded by ICOLD (1986, 2013), FEM modelling of dams is paramount in the safety evaluation of dam structures; for structures such as segmented arch dams built on valleys with complex topography, the detailed definition of the structure geometry – including the joints between the different blocks – and of the foundation rock mass is of primary importance in the FEM modelling of such systems. The high accuracy of UAV surveys makes possible the three-dimensional geometry modelling of important structural elements (i.e. construction joints) and/or of ancillary works (i.e. spillways, a stilling basin, weight blocks), as explained by Buffi et al. (2018). Therefore, the behaviour of such important elements can be investigated in static and dynamic conditions.

A survey by drone allows for the investigation of the current state of conservation of important infrastructures such as dams. It is the basis for the creation of an interactive photo and video database and for the metric reconstruction of the three-dimensional geometry of structures. In the spirit of obtaining an efficient and accurate as-built data collection, as summarized by Vacansas et al. (2015), the UAV technology is the main operative tool for the creation of BIM of large infrastructures. Moreover, respect than Laser Scanner technique, as employed by Barazzetti et al. (2016), UAV is faster

Figure 1: (a) The lake created by the presence of the dam, scale 1:500m (INGV); (b) The Ridracoli dam

and, for this reason, repeatable over time. The present work aims to explain the products of a UAV survey and their uses into the predictive and proactive maintenance of large structures such as dams. Case of study is the arch-gravity dam of Ridracoli, located in the village of Santa Sofia (FC, Italy), Fig.1a. The Ridracoli artificial lake and its dam represent an aqueduct infrastructures' milestone managed by Romagna Acque S.p.A.. So it is need to maintain the dam effectively and efficiently in order to guaranty safety and a long service life. These important aims require an innovative maintenance method moving from "run to failure" (reactive) approach to a predictive and preventive one. That needs the adoption of a BIM philosophy to collect any data about the dam and building a structural model for evaluating any deformation or stresses under several load conditions. As the first step, the BIM philosophy has the survey of the structure and of the surrounding topography on which a 3D model can be developed. This phase is useful both for collecting data (6d in BIM language) and for evaluating the structural behavior over time and, thus, the risk progressive levels which have to be assumed.

THE RIDRACOLI DAM AND ITS UAV SURVEY

The Ridracoli dam, managed by Romagna Acque Società delle Fonti S.p.A., is the key work of the Romagna aqueduct. The primary use of the Ridracoli reservoir is to supply drinking water of 48 municipalities in the provinces of Forlì-Cesena, Ravenna and Rimini and, since 1989, of Republic of San Marino, providing alone 50% of the entire water needs of the system. The secondary function of the reservoir is the production of hydroelectricity for the surrounding area. The reservoir surface area is 1.035km^2, it has a capacity of 33Mlm^3 and the total surface area of the drainage basin is 87.510km^2. The construction of the Ridracoli dam started in 1975 and it was completed in 1982. After the testing phase, in 1988 the reservoir became operational.

The structure. The simple concrete arch-gravity dam of Ridracoli has a double-curved structure, symmetrical with respect to the main section, resting on a *pulvino* foundation base that extends all around the perimeter of the abutments. The thickness progressively increases from the middle to the sides and along the vertical section from the top to the base, in line with the arch gravity construction type. The connection between the 27 cantilevers of the body dam was ensured by the injection of mortar (fluid concrete) into the vertical joints. The injections were performed through the inspection galleries midway between two blocks, in a radial direction and repeated several times in order to fill the contacts as much as possible. Moreover, during the concrete casting of adjacent blocks, plastic water-stop elements were placed along the perimeter of the inspection galleries and along the external perimeter of the joint. They have the dual function of preventing infiltration of the water and spillage of the cement grout, used for the suture of the joints. The principal dimensions of the structure are: maximum height of 103.50m and crest length of 432.00m, in the key section the top thickness is of 7.00m and the base thickness is of 36.00m. The structure has, in the central part of the crest, eight square free overflow (ogee crest) spillways, the water discharge throughout them

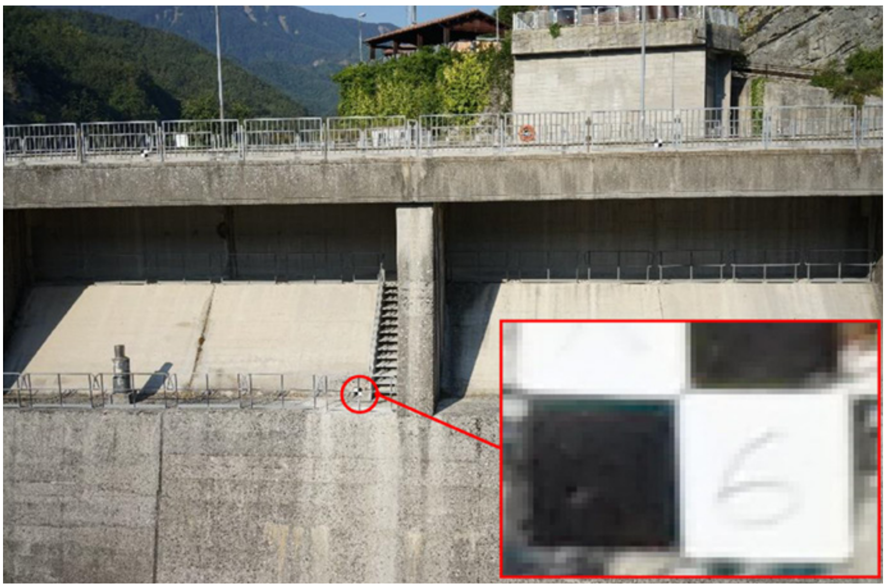
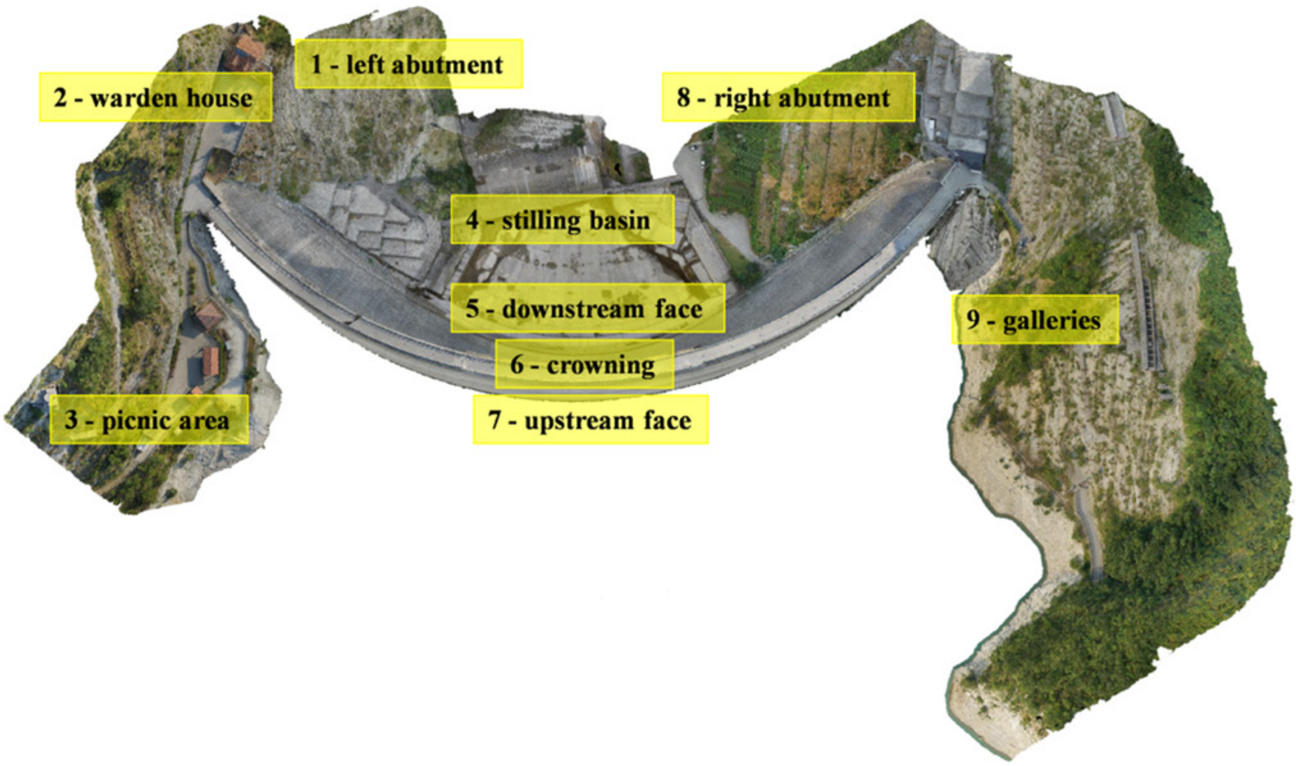


Figure 2: Frame of the downstream face, taken from 30m distance, in which, performing the maximum zoom, the number and the centre of the marker are perfectly detecteble



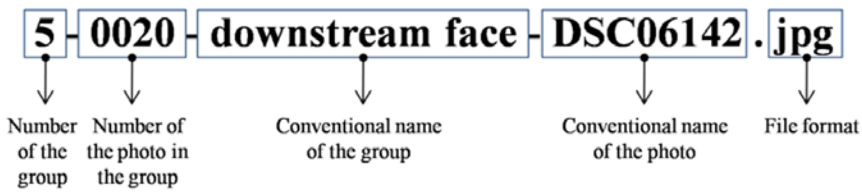
is governed by their geometry, with a maximum capacity of 600m^3/s. During overflow, the flowing water dissipates its energy in the stilling basin constructed at the foot of the downstream face of the dam. Moreover, the dam has a middle height sluice gate, a bottom sluice gate and a depletion sluice gate.

The survey. The Ridracoli dam has been the object of a technological comparison between traditional topographic instruments and unconventional photogrammetry conducted by UAV. The traditional topographic instruments are Total Station (TS30 Leica-Geosystems), GPS Satellite Station (1230 Leica Leica-Geosystems) and Laser Scanner (Z+F 5010 ZoellerFroelich). The UAV is a four propeller HIGHONE 4HSEPRO, with a max. take-off weight of 9kg and an autonomy of 18-30 minutes. The drone has a three-axis stabilized, remotely controlled Gimbal system with SONY Alpha 7R, 36.4 Mpix Full frame camera. Flight operations has been performed in manual mode for strips along the upstream-downstream direction of the structure by a first operator. Image-shooting operations has been followed by a second flight operator who has been able to assess the entity of overlapping frames to be suitable for aerial photogrammetry. The surveyed area is critical both for the strategic nature of the structure and for the presence of people although during the fly operation the access to the dam area has been closed. In August 2015, UAV flight operations were concentrated in a single day performing 19 flights lasting 15min/flight and providing a total of 4051 frames at 36 megapixel resolution. Fig. 2 shows the high resolution of the frames, it is a photo of the downstream face, taken from 30m distance, in which, performing a zoom, the centre and the number of the marker are perfectly detectable. The "Structure from Motion" technique allows for the reconstruction of the geometry of objects through the automatic collimation of points from a series of images. The result is the three-dimensional dense point cloud of the dam system and some parts of the surrounding area at which is associated an RGB (Red Green Blue) information. By means of the marker placement, the traditional topographic survey geo-references and validates the UAV one. Density, point, line and surface analyses have validated the accuracy of the UAV dense point cloud and confirmed the suitability of the UAV technique into the inspection of large structures such as dams. The influence of the number of the placed markers on the level of accuracy of the UAV dense point cloud has been also investigated, as described by Ridolfi, E., et al. (2017).

Figure 3: Interactive summary, in the yellow boxes the hyperlinks which connect to the photo groups of the zones

THE INTERACTIVE PHOTO AND VIDEO DATABASE

As mentioned above, the UAV survey has provided more than 4000 frames at a really high resolution. They are the basis for any subsequent elaboration. First of all, they are the elements for the creation of an interactive photo and video database of every part of the structure. The interactive summary, reported in Fig. 3, is the guide for the consultation of photos of each zone. In the interactive summary, hyperlinks connect to the group of photos which cover the area to which the same link is related to. The structure and the surrounding area are divided in the subsequent groups: left abutment, warden house, picnic area, stilling basin, downstream face, crowning, upstream face, right abutment and galleries, Fig.3. Tab.1 reports the number of frames taken for every area. Every photo is identified by a codification in which are reported, respectively, the sequence number of the group, the sequence number of the photo in the group, the conventional name of the group, the original name of the photo and the file format, an example is reported in Fig.4. Moreover, in every files are included EXIF (Exchangeable Image File) data, useful for storing interchange information: data and time the frame was taken and camera settings such as static information, camera model and manufacturer, and others, shutter speed, orientation (rotation), aperture, focal length, white balance and ISO speed information. In addition, the drone performed also a video of the structure and of the surrounding area, acquiring a general overview of the whole dam system.

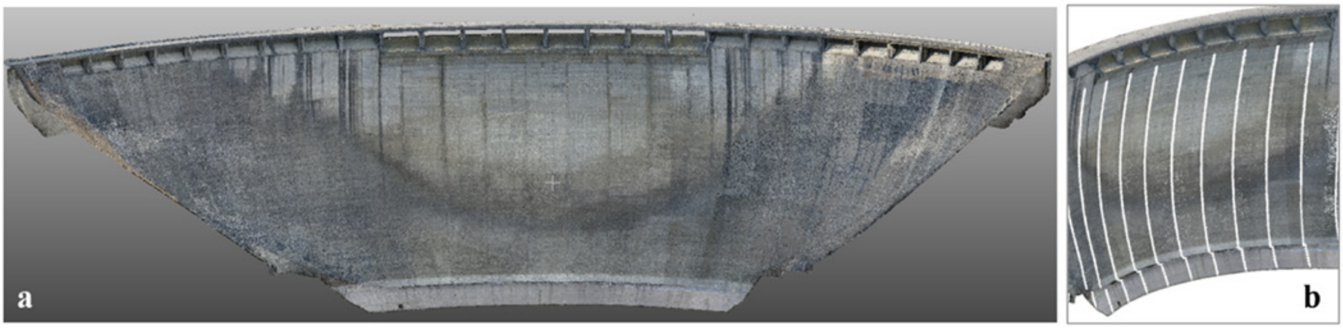


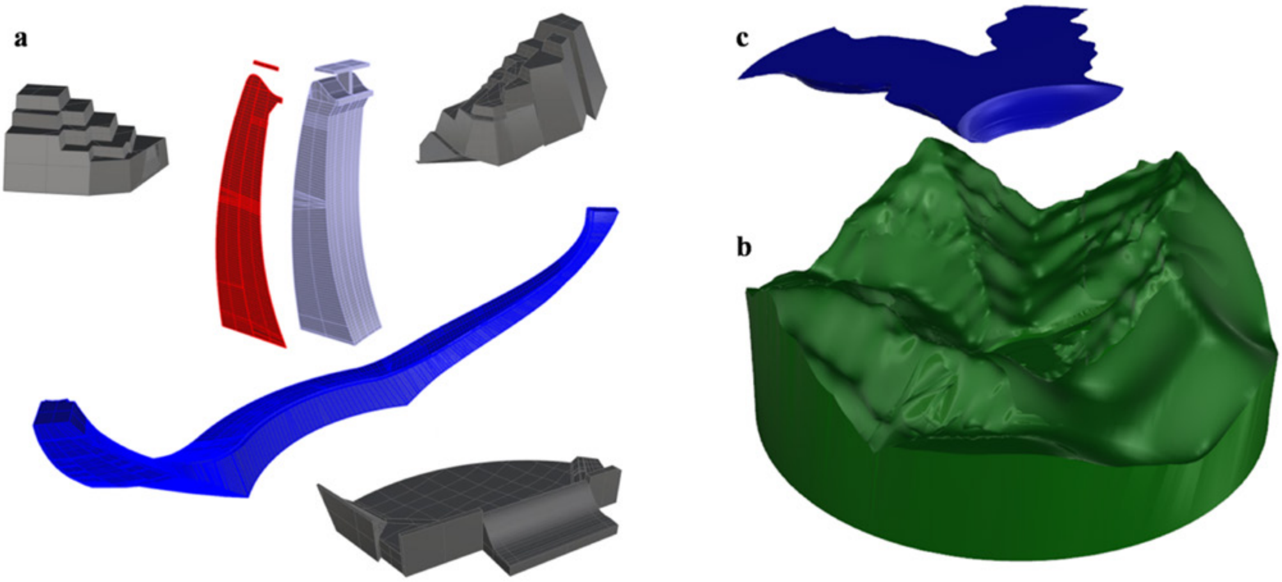
Groups	Number of frames
1 - left abutment	593
2 - warden house	183
3 - picnic area	197
4 - stilling basin	274
5 - downstream face	1630
6 - crowning	163
7 - upstream face	188
8 - right abutment	428
9 - galleries	395
Total	4051

THE SOLID MODELLING

As stated above, starting from the automatic collimation of the frames, the UAV dense point cloud of the structure, Fig. 5a, and of the surrounding area is obtained. This is the base for the construction of the solid model of the dam system. Significant points, that can describe elements with different mechanical characteristics, interactions or boundary conditions, are extracted. The criteria are based on the knowledge of the dam system elements, RGB information associated to the points and/or on the recognizable curvature changes. The selection operations are carried out using the CloudCompare® open source 3D point cloud editing and processing software, by means of the point list picking, Fig. 5b. Subsequently, the extracted points are exported into .txt format and they are imported to the Rhinoceros® commercial 3D modelling software. This is the environment in which data integration procedure with other data sets, such as design geometry, DEM (Digital Elevation Model) of the area and the bathymetry of the lake, are carried out. Connecting the significant points, lines are drawn: these are the contours for close polysurfaces that, including a volume, are solids by definition. The high accuracy of the survey allows for the modeling of some important details such as the vertical

Figure 4: Codification of a photo of the interactive database.
Table 1: Number of frames of each group





joints, the spillways, the stilling basin and the concrete blocks of the right and left sides, Fig. 6. Then, each element is imported in a FEA (Finite Element Analysis) software and, after assigning the properties, the parts are assembled and loads, interactions and boundary conditions are specified. Static and dynamic analyses are performed investigating the linear and non-linear behavior of elements.

CONCLUSION AND FUTURE DEVELOPMENTS

The uses and potential deployment of the UAV product are various. Compared to traditional topographic tools, although still necessary for georeferencing and validate the model, the UAV technique is faster and, for that reason, repeatable over time and cheaper. Moreover, some areas of large structures such as those of the Ridracoli dam, due to their reduced accessibility, would require considerable safety inspections work (involving climbers) and the simultaneous sharing of information among maintenance and management technicians would not always be possible. Therefore, the possibility to have a photographic record of every detail of the structure allows for shared participation and establishes a base level by which to monitor the evolution of the conservation status of the structure so that would

Figure 5: (a) UAV dense point cloud of the dam body; (b) point picking operation in CloudCompare®.
Figure 6: three-dimensional solid of important part of the dam system, (a) weight blocks, blocks, vertical joints, pulvino foundation and stilling basin; (b) rock mass; (c) water.

be possible to pass from a “run to failure” maintenance management to a predictive and proactive one. The speedy flight and its repeatability give the possibility to forecast rapid ageing in order to prevent a partial loss of safety with sustainable costs. For these reasons the UAV technique can be considered the operative tool for the development of BIM of such types of large structures. As with the FEM model, the solid elements developed in the pre-processing software can be characterized by their own mechanical properties. Moreover, the position, functionality and properties of the instrumentation can be included and photos of every details can be stored to provide documentary evidence of the state of conservation.

The management of important structures such as dams is not able to leave an accurate inspection of the state of conservation of the materials and a detailed three dimensional reconstruction out of consideration. The aim is the creation of a 4D model of the whole dam system which includes not only the “static” information but also those which can evolve over time. All the information related to an element would be merged in the same tool, avoiding data fragmentation between the company archives and allowing the immediate sharing of data between all the technicians are involved in, also in different places and time.

ACKNOWLEDGES

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4

Ifc-based Maintenance Budget Allocation

KEYWORDS: BIM, IFC, budget allocation, Facility Condition Index, Facility Management.

Maintenance budget appraisal and allocation is a fundamental activity for the definition of an effective Facility Management (FM) strategy. Once the maintenance policy is set by the assets' owner, facility managers are asked to compare different maintenance strategies (i.e. preventive vs. corrective) in order to provide a reliable and cost-effective maintenance budget. This can be hindered by unavailability of data for maintenance of building components. Nowadays, Building Information Modelling (BIM) provides plenty of data, but procedures are seldom focused on maintenance costs appraisal and this frequently leads to an intensive data re-elaboration. The objective of this research is to provide a precise maintenance budget appraisal according to different maintenance strategies through the Facility Condition Index (FCI), calculated starting from data stored into an Industry Foundation Classes (IFC) model. Data are stored in IfcAsset elements, using the related property sets. To overcome calculation needs, some additional attributes may be associated to elements and stored in custom property sets. The results of this research are a set of data, procedures and tools that allow the quantification and planning of maintenance expenditure, allowing a proper budget allocation. These procedures and tools answer the need of both designers during new constructions (to prepare the maintenance plan, as required by current Italian laws for public buildings) and asset managers during the digitisation of existing buildings (to store maintenance data and to rely on better appraisals). In this paper a demonstration is presented, with the purpose of showing the proposed methodology and tools. The demonstration has been carried out on some of the architectural and Mechanical, Electrical, Plumbing (MEP) components that mainly contribute to the annual maintenance expenditure.

INTRODUCTION

The built environment is currently characterised by an increasing complexity(Lu, Clements-Croome and Viljanen, 2010). On one hand the building is no longer featured only by physical characteristics,it is more and more included in an array of services to be provided to the users. On the other hand, the building intended as a physical entity, is being subject to a process of digitisationstemming from the massive use, in new buildings, of components and technologies requiring anICT-based (Information and Communication Technology) management approach. Within this context, the facility manager has to face a more and more complex physical asset producing and gathering a huge amount of data every day. Therefore, tools and techniques that should be employed for an effective Facility Management (FM) implementation must be addressed information complexity and uncertainty. Facility maintenance management (FMM) constitutes most (65%~85%) of the total costs incurred by FM activities(Lavy and Jawadekar, 2014). In this context effective methodologies and procedures for building management should be adopted for saving resources and for an improved sharing of information among stakeholders. Therefore, a BIM approach can be employed as basis for effective FM implementation(Pärn, Edwards and Sing, 2017). BIM can be defined as a digital based approach for management of information related to the buildings and the built environment(Re Cecconi, Maltese and Dejaco, 2017). Recently some demonstrations have proved the possibility to implement this approach also in the use phase of assets(Volk, Stengel and Schultmann, 2014; Chen et al., 2018). Therefore, this research addresses the issues related to the effective budget allocation through the use of the BIM approach. For this purpose, the IFC schema has been employed. IFC allows data exchange and interoperability through different professionals, software and phases of the Architecture, Engineering Construction and Operation (AECO) sector(ISO, 2013). For effective budget allocation and prioritisation of maintenance interventions, IFC schema has been employed in order to store the information related to maintenance planning and scheduling. IfcAsset has been associated to components belonging to the same building entity on which to perform homogeneous maintenance interventions. For that maintenance entity has been defined the standard maintenance profile and thanks to a Condition Assessment campaign the current maintenance status has been identified. These operations allow to define the Facility Condition Index (FCI) value of every single maintenance

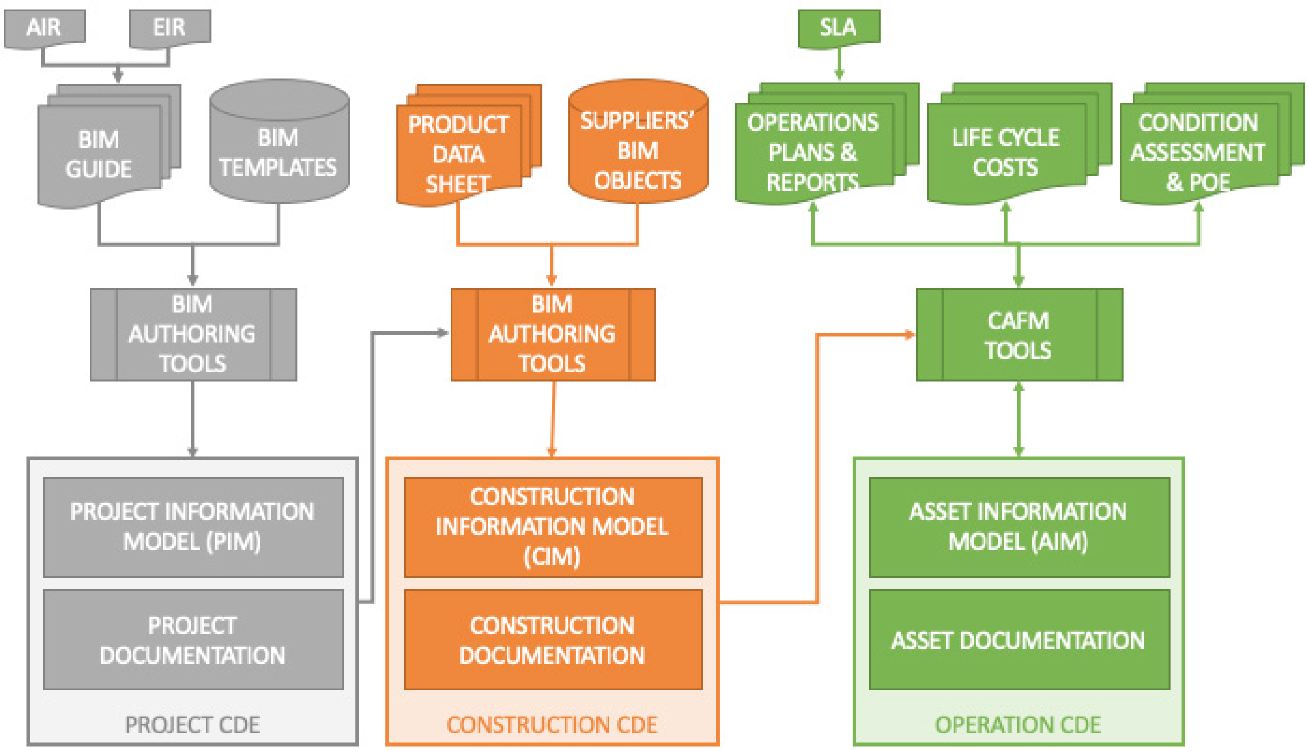


Figure 1: Information flows in design, construction and operation

entity. The FCI is one of the most used Key Performance Indicators (KPIs) for assets' assessment(Lavy, Garcia and Dixit, 2014), thanks to the possibility to scale the indicator from the single entity to the whole buildings portfolio(Re Cecconi, Maltese and Dejaco, 2017).In its basic form it is used for evaluation of cost of deferred maintenance (DM), over the Current Replacement Value (CRV) of the component(Rush, 1991).The FCI allows to quantify the maintenance expense in a scale from 0 to 100 (where 0 represents the best value) (Rush, 1991). The FCI, in this research, is used for a two folded aim: the maintenance budget allocation and the prioritisation of maintenance interventions. This approach has been tested on a case study concerning an office building in Erba, Italy. The paper concludes with some insights and further developments of the research.

STATE OF THE ART

BIM has shifted the way building information is managed, exchanged and transformed to enhance collaboration among project stakeholders(Eastman C, Teicholz P, 2011). Especially for what concerns the implementation of FM processes, the use of methodologies based on BIMis gaining momentum(Pärn, Edwards and Sing, 2017). This approach provides valuable support for the management of the large amount of data related to the planning, management and implementation of FM services (Re Cecconi, Maltese and Dejaco, 2017). However, from the very beginning, FM has been supported by the use of information management tools: from the first Computer Aided Facility Management (CAFM), to CAD, Integrated Workplace Management Systems (IWMS) and Computerised Maintenance Management Systems (CAFM)(Volk, Stengel and Schultmann, 2014). More recently, furthertheories and practices involving the use of BIM tools for FM have been developed(Chen et al., 2018). Theymainly deal with the possibility of integrating information on maintenance and management of building stocks and their parts into the collaborative approach typical of the BIM methodologies(Hosseini et al., 2018). This trend has led to the definition of a specific characterisation of the BIM approach(Volk, Stengel and Schultmann, 2014). The use of BIM for maintenance has also been promoted through the use of simplified IFC models like COBie(BSI, 2014), a subset of the IFC model, based on the Facilities Handover model view definition. Moreover,many examples of BIM use in the FM process can be found in literature, from the use of BIM in the condition assessment of existing buildings (Bortolini and Forcada, 2019) (Ani et al., 2015)to the automatic scheduling of facility maintenance work orders (Chen et al., 2018), from safety/ emergency management(Nicał and Wodyński, 2016) tothe creation of an asset register (Patacas et al., 2015).

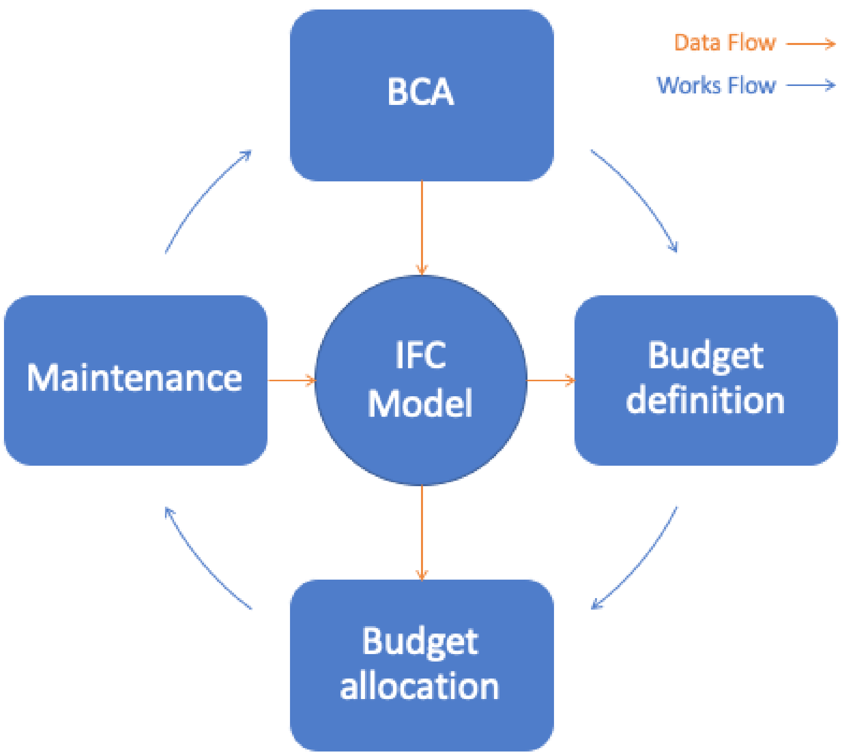


Figure 2: Research schema

RESEARCH METHOD

This research is part of a wider study exploring the use in FM of OpenBIM: a universal approach to the collaborative design, realization and operation of buildings based on open standards and workflows. This paper investigates the use of IFC, the core of OpenBIM, as the central source of information regarding the asset during its whole life cycle. Authors believe that many IfcPropertySetsand IfcEntitiescan be exploited to improve current FM practice, so the main objective of the research is to show how an IFC model can be the real centre of data aggregation.
The model and the documentation, contained in the Common Data Environment (CDE), is changing through the phases of the project (i.e. project, construction, operation) and are managed with different software (i.e. BIM authoring tools, CAFM tools) (Figure 1).

In this paper, only the part related to maintenance budgeting and scheduling is developed (Figure 2), aiming at scaling this process to other several activities, commonly time and effort consuming during assets operations (e.g. space management, contracting, rent, renovation, energy monitoring, etc.). The exchange of information is guaranteed using the IFC protocol: IFC allows not only the exchange of information but also the storage of relevant data about maintenance cost (i.e. maintenance budget) and scheduling (i.e. maintenance scheduling).

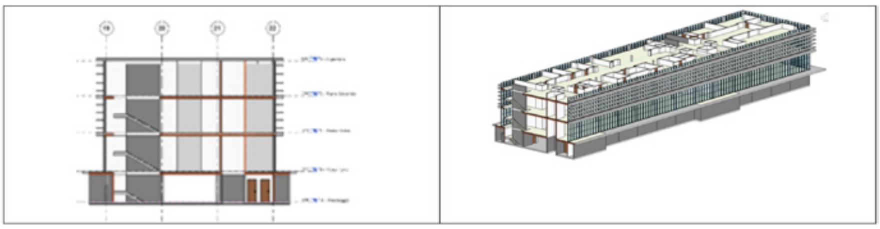
The research is willing to overcome an important limit of many BIM authoring tools: the association of data to groups of objects. For this purpose, the *IfcAssetcan* be employed, since it can be associated to single elements (e.g. *IfcMechanicalEquipment*) or to groups of objects (e.g. curtain wall, heating system). So, the IfcAssetcan bridge the gap between BIM authoring tools (object-centred) and management software (cost-centred): the *IfcAssetcould* be used as a centre of cost, with a budget assigned and maintenance scheduled.
In the demonstration section it is shown how to store maintenance operations datafor a curtain wallin an IFC model (2x4 Design Transfer View) and how to work on these data. The entity used for maintenance management, in this research, connected to the *IfcAsset* by the global identifier, is the *IfcProjectOrder*.

It is also possible to store list of data on a time series (*IfcIrregularTimeSeries*), by using *IfcAsset* in combination with the property set *IfcPerformanceHistory*, which allows to save one or more data with a time stamp (*IfcDateTime*[1:1], *IfcValue*[1:?]).

DEMONSTRATION

The methodology depicted in the previous paragraph has been validated through a demonstration on an office building located in Erba, Italy. The building is characterised by three floors above the ground and one underground. Currently, it is occupied by a construction firm and a notary firm. The BIM model has been created using as-built 2D drawings following the information requirements analysis: the objective was to create a low LOD and high LOI model with all the data needed for the operational phase. All spaces and main components (architectural and MEP) have been modelled. In Figure 3 the BIM model of the case study is presented.

The IFC model of the building has been developed and all data concerning maintenance management and implementation have been collected and stored. The IfcAssetattributes has been used to match BIM objects with costs associated to maintenance operations done or to be done (Figure 4).
Table 1 shows in a simplified way how the maintenance cost profile for each component to be maintained (*ifcAsset*) has been developed. For synthesis reasons,Figure 5represent the IFC characterisation of maintenance operations for the curtain-wall (south façade). *IfcAsset* has been used as the maximum level of aggregation for components, which allows to define homogeneous maintenance interventions.



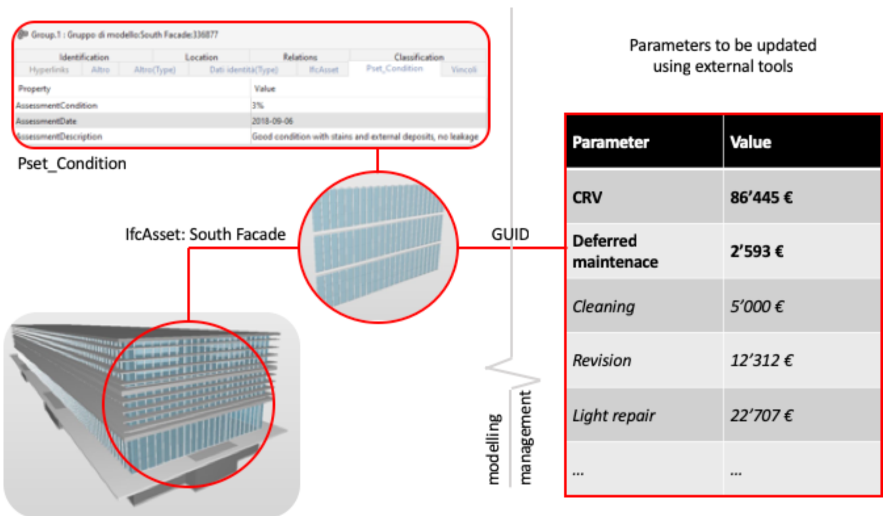
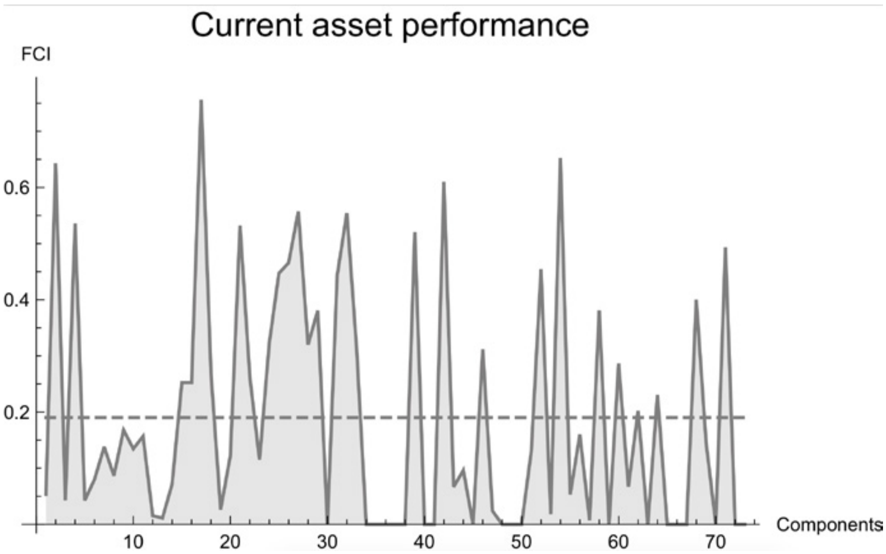


Figure 3: BIM model of the case study
Figure 4: IfcAsset implementation and external parameters

Entity		*Name*	*Maintenace operations*				
			Cleaning	*Revision*	*Light Repair*	*Medium repair*	
Project Order (IfcProjectOrder)	*Attributes*	Predefined Type (IfcProjectOrderTypeEnum)	MAINTENANCEWORKORDER	MAINTENANCEWORKORDER	MAINTENANCEWORKORDER	MAINTENANCEWORKORDER	…
		Status (IfcLabel)	PLANNED	PLANNED	PLANNED	PLANNED	…
		Long Description (IfcText)	Pulizia lato esterno dei vetri e della struttura con detergenti appositi	Revisione montanti e traversi in alluminio, cerniere e gurnizioni	Piccole riparazioni di infissi in metallo, compresa raddrizzatura di bordi, regolazione della chiusura,	Medie riparazioni di infissi in metallo, compresa raddrizzatura di bordi, battute, montanti,	…
	Pset_ProjectOrderMaintenanceWorkOrder	Work Type Requested (IfcText)	Light intervention	Light intervention	Light intervention	Medium-level intervention	…
		Contractual Type (IfcText)	Global Service contract	Global Service contract	Global Service contract	Global Service contract	…
		Maintenace Type (PEnum_MaintenanceType)	SCHEDULED	SCHEDULED	SCHEDULED	CORRECTIVE	…
		Fault Priority Type (PEnum_PriorityType)	LOW	MEDIUM	MEDIUM	MEDIUM	…
		Location Priority Type (PEnum_PriorityType)	LOW	LOW	LOW	MEDIUM	…
		Scheduled Frequency (IfcTimeMeasure)	12,0	24,0	24,0	36,0	…
Cost schedule (IfcCostSchedule)	*Attributes*	IfcCostScheduleTypeEnum (IfcCostScheduleTypeEnum)	ESTIMATE	ESTIMATE	ESTIMATE	ESTIMATE	..
Cost Item (IfcCostItem)	*Attributes*	Name (IfcLabel)	Total cost	Total cost	Total cost	Total cost	..
Cost Value (IfcCostValue)	Attributes	Applied Value (IfcText)	5.000,00	12.312,00	22.707,00	20.277,00	..
		Cost Type (IfcLabel)	NULL	NULL	NULL	NULL	..



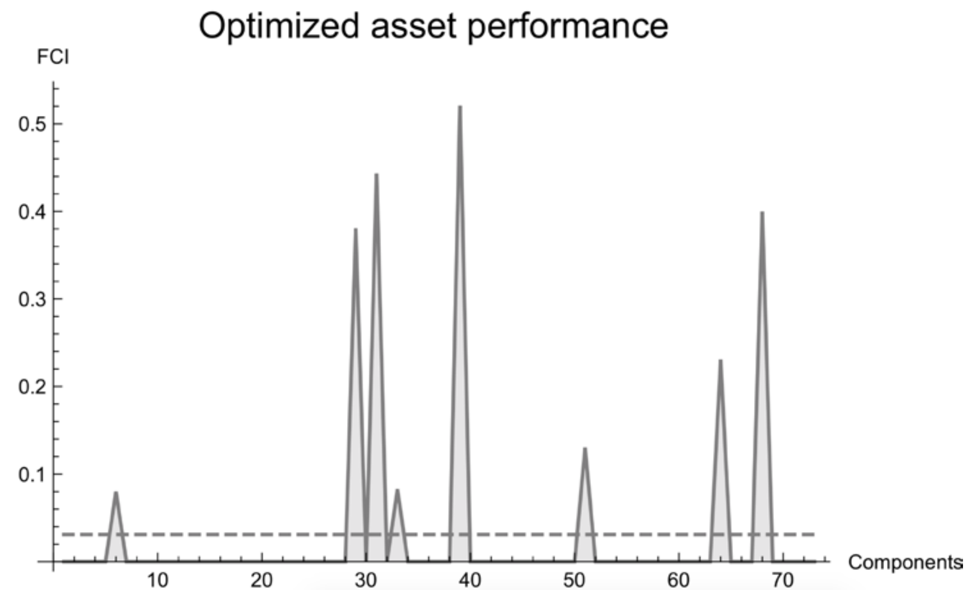
DISCUSSION AND CONCLUSIONS

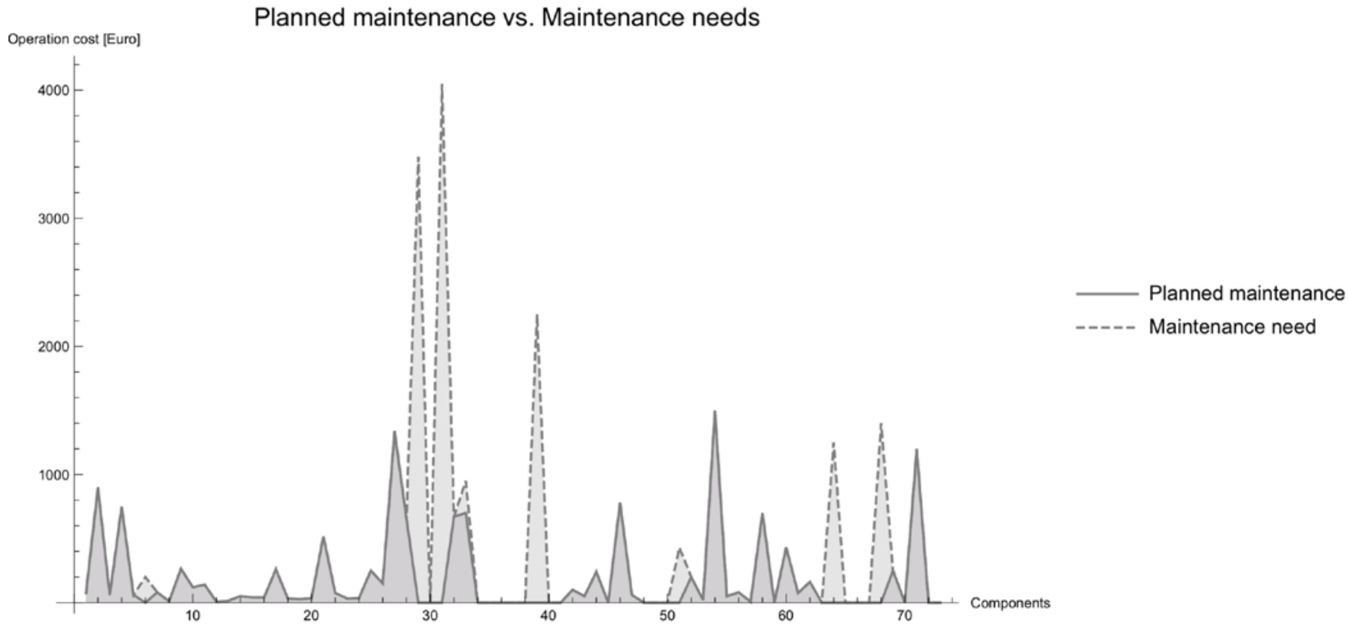
The data inserted in the model thanks to a Building Condition Assessment (BCA) procedure, the survey and the analysis of FM documents, resulted in 85 deferred maintenance operations. These have been found during the BCA on 73 components surveyed. The total average FCI resulted equal to 19%, as shown inFigure 6.

A simulation with a budget constraint, set to half of the deferred maintenance costs has been carried out. Therefore, an optimization algorithm has been run. This led to schedule 69 out of 85 maintenance operations. The new FCI after the computation is 3.11% (Figure 7), which means an FCI decrease of more than 83%, with half of the economic resources required to perform all deferred maintenance operations.

Figure 8 shows the overlapping of the curve related to the total maintenance interventions to be accomplished to restore the FCI value equal to 0 (dashed line)and the curve representing the

Figure 5: Definition of curtain-wall facade maintenance profile trough IFC.
Figure 6: Components' FCI computed after the BCA



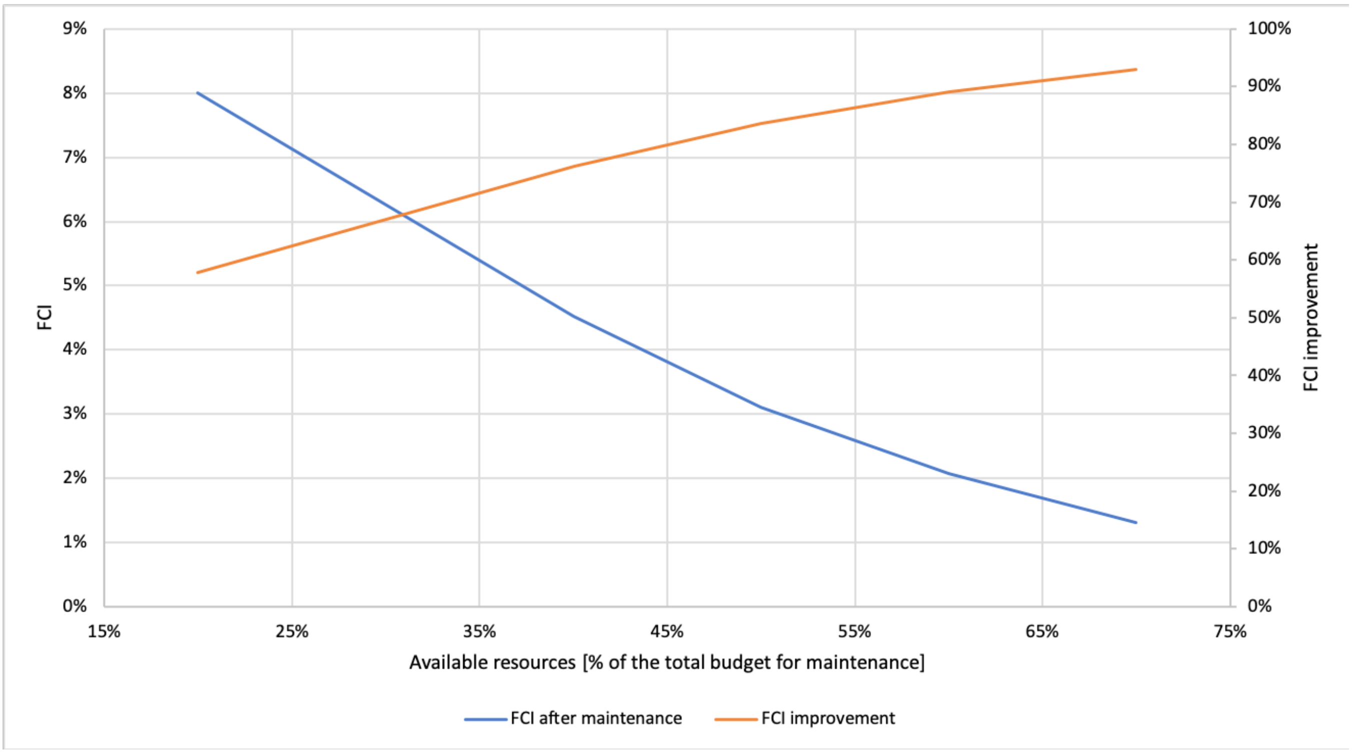


interventions carried out with the DM recovering budget set to 50% (solid line). The optimisation algorithm allows to significantly reduce the maintenance expense for each IfcAsset and reducing spending peaks.

Thanks to the data inserted in the model and a further elaboration is possible to evaluate the FCI according to budget changes (Figure 9). This allows to allocate the budget over different years and to compare different assets/ buildings of a portfolio. Moreover, it can be the basis for the creation of scenarios and for the annual budget allocation, providing a reliable basis for assets comparison.

To conclude, it can be stated that through the research presented in this paper the possibility to exploit OpenBIM and IFC for facility maintenance management has been demonstrated. In particular, the case study showed the possibility to handle data contained in IFC both as input and output of the process (e.g. initial and final FCI of an IfcAsset). It is important to remember that IFC is an exchange protocol and the data must be elaborated with an external software, tool or plugin.An algorithm has been developed by the authors, but this has

Figure 7: FCI of each component after the scheduled maintenance
Figure 8: Planned (optimized) maintenance vs. Maintenance need (deferred maintenance)



to be implemented into a management software, to be exploited into the market.Moreover, the methodology allows also to reduce the costs related to inefficientdata management (loss of information) through the whole life cycle of the building. nevertheless, to implement effectively the proposed methodology, it is necessary that the owner defines precise guidelines for modelling and updating the BIM model.

Figure 9: FCI after maintenance and FCI improvement according to the maintenance budget

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5

Innovative Approach to the Configuration of Smart Buildings

KEYWORDS: smart building, building configuration, Building Information Modelling, client, user

In the construction sector, a strong push for innovation is due to the demand for high quality standards of living that can be related to safety, accessibility, usability, energy efficiency, as well as sustainability in terms of construction and management costs.The demand is becoming increasingly "sustainable" also because it is increasingly aware of the limited availability of resources (fossil fuels, water, etc.) and the simultaneous need for environmental protection. In order to respond to the demands of an increasingly demanding market, we identify the need for an innovative approach with the characteristic of being increasingly "friendly" for the future user.
The work aims in fact, with the help of BIM computerized tools, to develop a prototype project intended to create low-cost and energy-efficient residential typologies, involving the user in a sort of guided path designed to explain, within a pre-constituted grid, its needs, realizing a real configuration of the building, directly related to obtainable estimations, based on:

- use of innovative building materials and components for construction;
- application of strategies for the optimization and rationalization of the activities envisaged during the execution phase;
- extensive use of remote control and management systems and monitoring of performance obtained in the management phase.

The involvement of the client/user in all phases of the building process presumes an innovative approach oriented to the development of all those strategies aimed at empowering and making the user aware, especially in the management phase, depending the achievement of energy efficiency objectives precisely on the user's behavior.

INTRODUCTION

The European reference legislative framework

The European Union pursues the goal of developing a sustainable, competitive, safe and decarbonised energy system by 2050. In fact, by 2050, Member States will have to adopt measures to achieve the long-term emission target of greenhouse gases and decarbonise the housing stock, which accounted for around 36% of all CO_2 emissions in the Union. The Paris agreement on climate changes in 2015 encourages the Union's efforts to decarbonise its housing stock. Taking into account that almost 50% of the Union's final energy consumption is used for heating and cooling, of which 80% in buildings, the achievement of the Union's energy and climate objectives is linked to the efforts of this last to renew its building heritage, giving priority to energy efficiency, using the principle of "energy efficiency first", as well as evaluating the use of renewable energy. The Directive 2010/31/EC imposed on member countries the construction of new buildings with almost zero energy consumption (Nearly Energy Zero Building). The Directive 2018/844/EC modifies the directives 2010/31 and 2012/27/CE and clarifies and implements the objectives for an ideally decarbonised building sectorfor a NZEB building park in 2050. Long-term renovation strategies will have to have clear and measurable objectives, as well as initiatives to support the development of infrastructures for the electromobility. The new Directive also promotes economically efficient renovations, introduces an indicator of intelligence for buildings, simplifies inspections of heating and air conditioning systems. Among the objectives pursued are also to underline those that encourage the use of information technology for efficient buildings, and increase the role of consumers, informing and protecting them from the energy poverty.

The smart building

The current approach of European legislation encourages the construction of smart buildings, where innovative solutions are widely used. Smart buildings are created when these solutions provide for multiple generation systems, managed by supervisory and control systems that make extensive use of Information and Communication Technologies (ICT) and adopt logic that meets economic, environmental and/or of comfort performances, in response to the needs of users. In particular, in a smart building, users are involved in the control of energy flows and all possible user needs are recognized and taken into account in terms of comfort, health, indoor air quality, safety, as well as in the identification of operational requirements.

The current context and the perspectives of the construction sector

In this context, the construction sector has a fundamental role and consequently will have to transform itself facing to the challenge of the energy performances required both for the new building and for the energy requalification of the existing heritage. Technologies, solutions, materials and advanced products are in fact already available on the market, but so that the use of innovative technologies and the consequent investments can find a concrete application it is necessary to develop new models of design approach. In the construction sector, a strong push for innovation is due to the transformation of housing demand from quantity to quality, where quality means more security, sustainability, accessibility and usability. The demand has become "sustainable" also because it is aware of the limited availability of strategic resources (fossil fuels, water, etc.) and of the need to take account of environmental protection. Innovation in the energy and environmental fields and sustainability in construction offer the possibility of minimizing the impact of the building process on the environmental, social and economic context and offer concrete conceptual and operational tools, with which the sector can be restarted. Aiming at the innovation of the building sector, integrating renewable sources and energy efficiency, is a prospect of great opportunities to relaunch the sector that must be pursued by all means.

Work's goal

The work aims, with the help of BIM computerized tools, to develop a prototype project in order to create low-cost and energy-efficient residential typologies, involving the user into a kind of guided path designed to explain, within a pre-constituted grid, its needs, realizing a real configuration of the building, directly related to estimates. The involvement of the client / user in all phases of the building process, assumes an approach innovative and oriented to the development of all those strategies aimed at empowering and making the user aware especially in the management phase, depending precisely on the user's behavior the achievement of energy efficiency objectives.

THE CLIENT/USER KEY ROLE

In view of the above, the role of the client/user is essential and strategic for the pursuit of the objectives set out and clarified by the Directive 2018/844/EC. In this paper we aimed to centralize the role of the client/user not only for the achievement of the objectives of the Directive, but also for the respect of the relationship between technological choice and estimate of the relative cost, also including this last aspect in the in the area of sustainability. From this point of view, it is necessary to make the client/user aware, as a fundamental operator of the building process, from the initial moment to the building management phase. In fact, it is believed that an efficient management during the operation phase is essential to ensure the expected results, as well as a correct design choice. The following is a summary of the working methodology developed in the various phases that can be summarized as follows:

1. Definition of the spatial functional system, of the technological packages used and of the elements useful for the purpose of estimating;
2. Creation of families in Revit of the studied elements;
3. Generation of the abacuses in Revit, from which to extract the necessary quantities to be included in the estimate sheet;
4. Definition of rules through the STR-Vision software, thanks to which, once the Revit model has been imported, an instant parametric estimate can be generated.

	REFERENCE GRID								
FUNCTIONAL - SPATIAL	Residential type	Detached	Semidetached			Terraced			
	Number of users	1	2	3	4	5	6	7	8
	Number of adults	1	2	3	4	5	6	7	8
	Number of children	0	1	2	3	4	5	6	7
	Day area	Living - Kitchen - Dining	Living + Kitchen - Dining			Living + Kitchen + Dining			
	Master bedroom	0	1			2		3	
	Single room	0	1			2		3	
	Double room	0	1			2		3	
	Studio/Office	0	1			2		3	
	Bathrooms	1	2			3		4	
	Garage	Single in	Double in			Single ext		Double ext	
	Other spaces								
ASPECT	Tyoe of fixtures	PVC	Wood			Aluminium			
	Floor finishing	Whole ceramic	Whole wood			Ceramic for day area and wood for nigh area			
	Shielding system	Blinds	Blackout curtains			Shutters			
	Number of floors	1	2			1 with loft			
TECHNICAL-ENERGY	Type of structure	X-Lam wood	Concrete			Brick			
	Type of installation	Radiant floor				By air			
	Transmittance values opaque surfaces	Minimum of legislation				Best values			
	Transmittance values of fixtures	Minimum of legislation				Best values			
	Plot possesion	Yes				No			

Table 1: Reference grid to identify the needs of the client/user in the case of a residential building

Useful documents for briefing

The first step to realize the involvement of the client/user was to implement a reference grid useful for identifying needs. In fact, it is well known that a correct focusing of needs sets the premises for a correct design that guarantees an optimal use of technological resources and, consequently, an optimal use of energy resources in the management phase.In the briefing the client/user can fill the reference grid, marking the desired box. The table can be supplemented, possibly by more descriptive documents, in which, by answering open questions, the identification of users' needs is completed. The grid illustrated in table 1, will allow to identify the building to be designed, from an environmental, technological and functional/spatial point of view.

DEFINITION OF THE TECHNOLOGICAL SYSTEM

It is established that the following conditions must be met as a priority:

- the default building complies with the provisions of the D.M. 06/26/2015;
- for each package the thermo-hygrometric verification of the technological packages is satisfied;
- the type of foundation used and its size depending on the size of the same;
- the production of energy is entrusted to a photovoltaic system with power greater than or equal to 4KWp.

The client/user has the possibility to choose respectively for vertical structures, among the following three technologies:

- structural partitions in reinforced concrete with disposable formwork

WINDOW Family
Window – 1 door – roller blind
Window – 1 door – blinds
Window – 1 door – blackout curtain
Window – 2 door – roller blind
Window – 2 door – blinds
Window – 2 door – blackout curtain
French window – 1 door – roller blind
French window – 1 door – blinds
French window – 1 door – blackout curtain
French window – 2 door – roller blind
French window – 2 door – blinds
French window – 2 door – blackout curtain Velux

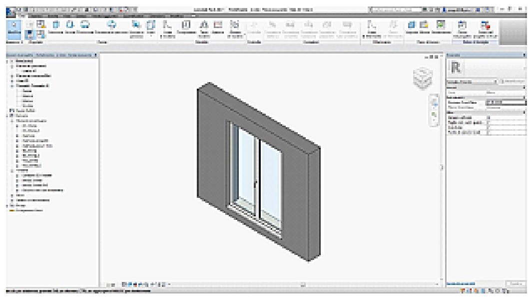


Figure 1: Example of displayed return of the window family

in eps;
- rectified brick;
- wooden panels in CLT.

Compatibly with the choices made for the vertical structure, for the roof structure, the possibility of choosing between a wooden structure and reinforced concrete is given. The client/ user can then choose the type of frame and any finishing components.
The work continued in-depth analysis and study of the price incidences of buildings already built similar for technology and performance. Prices have been associated with technological packages and parameterized to surfaces. In this way, the client/user responding to the format is not only able to define the desired building but also its cost. The item of the construction of the building site has been inserted by default and its cost calibrated according to the size of the building thus obtaining a real online estimate.

DIGITISATION OF THE BRIEFING

Following the above logic, the second step of the work consisted in the online transfer of this methodology. To this end, a digital platform has been specifically designed to allow the client/user, within the constraints set out above, to make the functional/spatial, environmental and technological choices proposed and define the level of energy performance of the building. In this way, the client/ user responding to the format is not only able to define the building that meets his needs, but also its cost, thus obtaining a true online estimate. This data necessary for both the designer and the manufacturer are thus available directly on the network. This computer system will also allow to control costs throughout the life cycle of the building through the use of BIM tools. The whole process has been implemented through Revit (BIM software). The families of the elements and packages most used in buildings were created, and the schedules were managed by formulas contained in spreadsheets; in this way has been possible to improve the computation process.

FAMILIES CREATION

Revit families are used to create building models. Each family has very precise and measurable parameters. It must be specified that the designer must choose what kind of family to use to represent a certain element of reality. Usually the names of the families indicate the purpose of the family itself (i.e. the Wall family indicates that with that input key a wall can be created), but the use of a key is not univocal and can be useful for the creation of other elements. By way of example, in Figure 1, the family of windows and French windows specially designed is shown.

SCHEDULES CREATION

Revit schedules, realized for all construction elements, are summary tables useful to computation. The peculiarity is that these schedules, in order to extrapolate the necessary information, must be set with specific grouping and filtering formulas, so as to exclude irrelevant information. Thus, ordered abacuses have been created that can facilitate computation. In this way, the completion of the final spreadsheet for the creation of the estimate is easier and faster. Furthermore, in the case of project variants, the quantities of the abacuses are instantly updated.

COMPUTING IN STR-VISION

STR-Vision is a software for the management of orders and for the metric-estimation computation of orders. One of its strengths is the interoperability with BIM, as with the import of the Revit model in STR it is possible to generate computations and complete estimates. The work that was performed at this stage was to allow communication between Revit and STR. To do this, we worked in the STR environment so that the software would recognize the Revit families, extracting from these the desired quantity correctly. The process took place as follows:

1. Creating a model in Revit with all the useful families present in the model itself, in order to create a file that contains all the families, ready to be imported and recognized in STR (figure 2).
2. Export of models in .IFC 2x3 format.
3. Opening of STR-Vision.
4. Creating a Catalog of Rules. Before creating the rules, we need to create a Catalog (on System Settings) that will serve as a container to the rules.
5. Creation of articles: it is in fact necessary to create all the articles to be used. The articles are found in a Price List created ad hoc in the "Price list" section. Each item has a unique Reference Code, a short description, a unit of measure and a price. These are the basic parameters that each article must have. Articles can be added, modified or deleted at any time, paying attention to the hierarchy that commands them. Subsequently the families of the Revit model will have to be "connected" with these articles, in particular to the unit of measure of the article.
6. A new Project has been created, which can be found in "Projects and Orders". Only once created a new project, it will be possible to import the IFC model created in Revit. In "IFC models" you can add the .ifc file and, once active, use it.
7. In the Budgeting section, we must now do the so-called "Collections", that is, make sure that STR detect the families of the .ifc model linking them in the List Items.
8. The imported model is displayed and proceed with the measurements. The measurements must be made by setting the search conditions, filtering and selecting the information useful in the selected family (cubic meters, square meters, descriptions, etc.). Once the surveys have been generated, they will be connected to the chosen family.
9. Finally all Rules to compute families have been created.
10. Once this is done, you can use these rules for any future estimate, of course only if the same families will be used in Revit.
11. It goes therefore in the BIM section and the Parametric Estimate is used. Once the Catalog is loaded all the rules created are loaded and the automatic estimation of the software can be started. STR generates the Automatic Collections at this point.
12. After generating the surveys, a print template has been created and the estimate can be printed and presented.

ILLUSTRATION OF ON LINE USE OF THE PLATFORM

In succession are shown below, for example in the case of residential building, the various steps that the client/user must directly perform on a hypothetical on line platform, in order to be able to create a preliminary estimate. The first page of a building site specifically created in order to allow configuration by the client/user, should show an image in which he can choose the type of residence as shown in Figure 3.
After this step, the client/user must choose the construction technology of the vertical structure, and of the roofing. Three systems are foreseen for the vertical

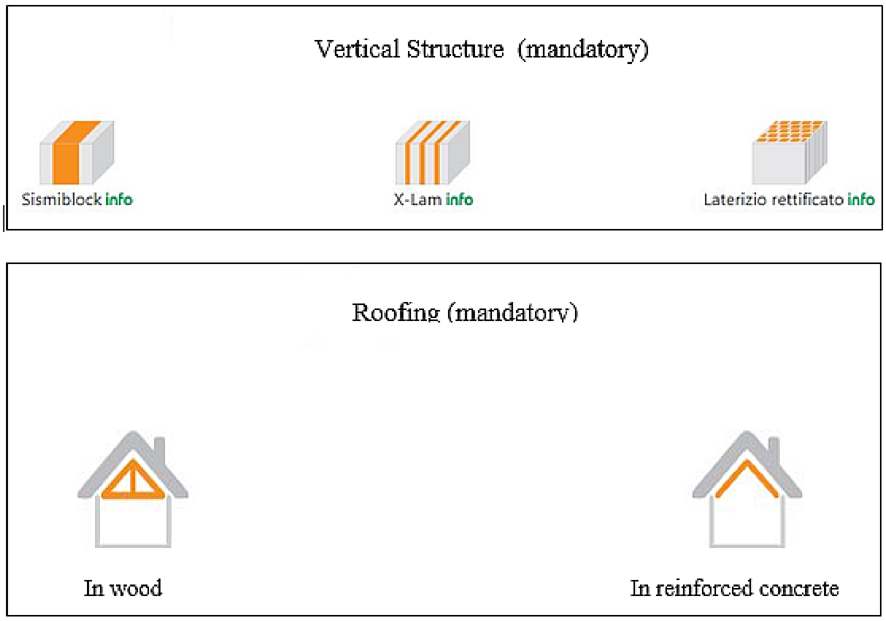


Figure 3: Initial screenshot in which the client/user can choose the type
Figure 4: Screenshot for selecting the vertical structure technology and Roofing

structure: partition in reinforced concrete with disposable formwork in eps (icon on the right in Figure 4), in clt (central icon of Figure 4), in rectified brick blocks (icon on the right of Figure 4) and for roofing systems: wooden or reinforced concrete structure.
The next step involves the definition by the client/user of the surfaces of the environmental units, such as living room, kitchen, living-dining room, laundry and power plant, garage and porch.
A final step consists in the choice by the client/user of the type of electrical and thermo-mechanical system, of sewage and sub-services and of the number and size of the bathroom w.c.unit allowing the choice in relation of the dimension between three types, small equal to 4 sqm 4, medium 6 sqm and big 8 sqm, as illustrated in Figure 5.
Now the estimate can be printed in a summary sheet. In this way, through simple steps on one side, the client/user has configured his home and quantified the cost, on the other hand the designer and/or the manufacturer has, in a clear and documented manner, knowledge of the exact needs of the client/user.

DESCRIPTION OF THE NZEB RESIDENTIAL BUILDING AS ARESULT OF THE GUIDED DESIGN

The case study, designed from scratch, and chosen for the present work is a semidetached house, Figure 6. The building is spread over 2 floors above ground, and consists of two units that share the central spine wall. It is assumed to be located in the province of Treviso. The basic dimensional data of the building and the rooms are summarized below. Altitude 6 meter. above sea level, in the climate zone E.
On the ground floor there are porch, garage and laundry room and the following environmental units: entrance, living room, kitchen, hallway, bathroom.
On the first floor there are the following environmental units: hallway, two double bedrooms, a single bedroom, a walk-in closet, a bathroom and a lodge.

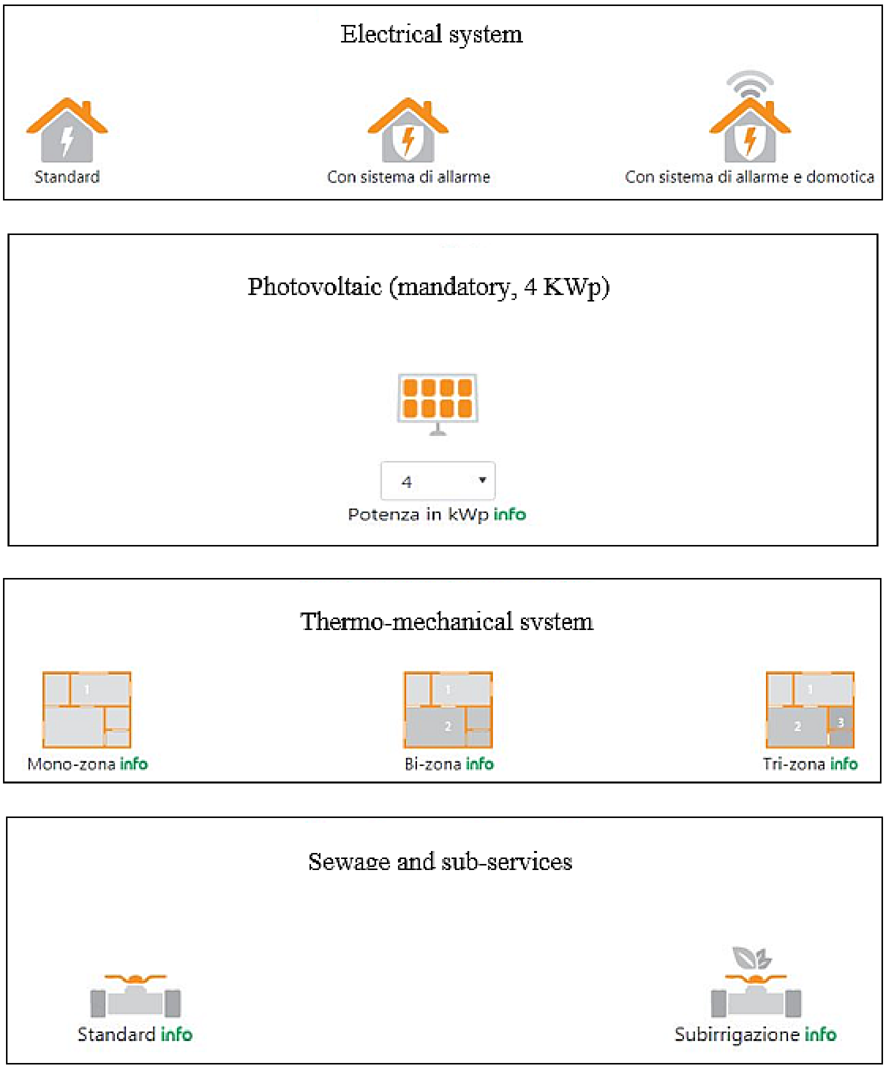


Figure 5: Screenshot for selecting the system type
Figure 6: Semi-detached house model realised in BIM

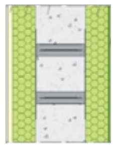
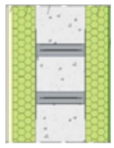
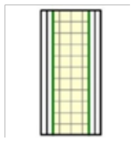
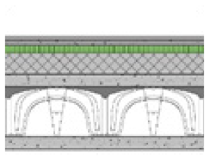
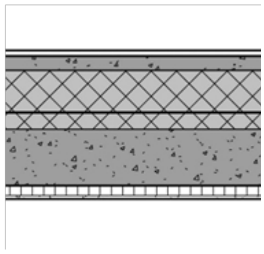
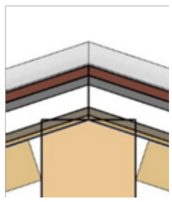
MODEL IN REINFORCED CONCRETE AND EPS		
Element	**Description**	**Image**
Load-bearing perimeter wall and wall between heated –unheated rooms	External plaster - 7 mm External EPS - 124 mm Reinforced concrete - 192 mm Internal EPS - 64 mm Plasterboard finishing - 12,5 mm	
Load-bearing internal wall between heated-unheated rooms	Plasterboard finishing - 12,5 mm External EPS - 64 mm Reinforced concrete - 192 mm Internal EPS - 64 mm Plasterboardfinishing - 12,5 mm	
Internal wall	Plasterboard double layer - 25 mm Metal and stone wool structure - 75 mm Plasterboard double layer - 25 mm	
Floor on the ground	Floor finishing - 15 mm Screed - 50 mm Nylon Foam polystyrene - 60 mm Integrated systems lightweight screed - 170 mm Casting completion - 100 mm Plastic Iglù Formwork- 400 mm Lean concrete foundation 100 mm	
Slab floor	Floor finishing - 15 mm Screed - 50 mm Nylon Lightweight screed - 170 mm Casting completion – 60 mm Airfloor slab floor in concrete and Polystyrene – 200 mm Metal structure – 35 mm Plasterboard slab – 12,5 mm	
Roofing	Elyforma metal layer – 45 mm Metal structure – 30 mm Polyurethane – 100 mm Mineralised wood wool 35 mm Vapor barrier Wooden boards – 21 mm Wooden roof beams	
Windows	PVC	
Air conditioning	Heatingpump + Accumulation + ATU	
Photovoltaic	4 kWp photovoltaic system	
Electrical	Electricalsystem + AAL system	

Table 2: Model in reinforced concrete and EPS

Analysis of construction techniques, materials and components

The construction techniques, materials and components considered for the 3 design models are analyzed. The evaluations on the choice of the technological packages analyzed are shown: Load-bearing walls in reinforced concrete and EPS, in CLT and wood fiber, in brick and stone wool.

Concrete model with disposable formwork in Eps

The model with reinforced concrete bearing walls considers 16 possible types of wall. The reinforced concrete is cast into EPS formwork, which act as both a formwork and an insulating layer. The thickness of the internal insulating layer in EPS is 64 mm, the external insulating layer provides the following possible thicknesses: 64 - 94 - 124 - 184 [mm]. For reinforced concrete, the expected thicknesses are: 142 - 162 - 192 - 250 [mm]. Considering the minimum transmittance value equal to 0.26 W / m2K as foreseen by the D.M. 26/06/2015 for buildings in band E of the year 2021, all the walls are compliant. The nZEB stratigraphy of the project is shown in table 2. As regards the external thickness of EPS insulation, it was decided to use the 12.5 cm one for both the external walls and between the heated and non-heated rooms. For the spine wall located between the 2 garages (ground floor) and between the two bedrooms (first floor) there are provided coats of 6.4 cm on both sides because between environments that have the same temperature does not occur heat exchange.

Wall in Cross Laminated Timber and wood fiber

The model provides the supporting structure in CLT that can vary in thickness and the layer of insulation in wood fiber that can vary in density and thickness. The package has been studied varies with the thickness of the layers, at steady state and at periodic system stabilized, to check if there are phenomena of superficial or interstitial condensation and it has been verified that the optimal solution is that that foresees for every technical element the following stratigraphy:

- Load-bearing perimeter wall: External plaster - 7 mm, Hard wood fiber - 40 mm; Wood fiber - 80 mm; CLT - 100 mm; Acoustic wood fiber – 50 mm; Plasterboard finishing - 12,5 mm;
- Load-bearing internal wall between heated-unheated rooms: Plasterboard finishing - 12,5 mm; Acoustic wood fiber – 50 mm; CLT - 100 mm ;Acoustic wood fiber – 50 mm; Plasterboard finishing - 12,5 mm;
- Internal wall: Plasterboard double layer - 25 mm; Metal and stone wool structure - 75 mm; Plasterboard double layer - 25 mm
- Floor on the ground: Floor finishing - 15 mm; Screed - 50 mm; Nylon; Foam polystyrene - 60 mm; Integrated systems lightweight screed - 170 mm; Casting completion - 100 mm; Plastic Iglù Formwork- 400 mm; Lean concrete foundation 100 mm;
- Slab floor: Floor finishing - 15 mm, Screed - 50 mm; Nylon; Lightweight screed - 170 m; Acoustic cladding; CLT load-bearing slab floor – 180 mm, Metal structure – 35 mm; Plasterboard slab – 12,5 mm;
- Roofing: Elyforma metal layer – 45 mm, Metal structure – 30 mm; Polyurethane – 100 mm; Mineralised wood wool 35 mm; Vapor barrier; Wooden boards – 21 mm; Wooden roof beams.

This stratigraphy is optimal for transmittance (0.27 (W / m²K), for winter comfort (0.18 W / m²K), for summer comfort being the decrease factor of 0.055 and a time displacement equal to 17 hours. Also the acoustic comfort is optimal, having a soundproofing power of 39.7 dB. This stratigraphy is also

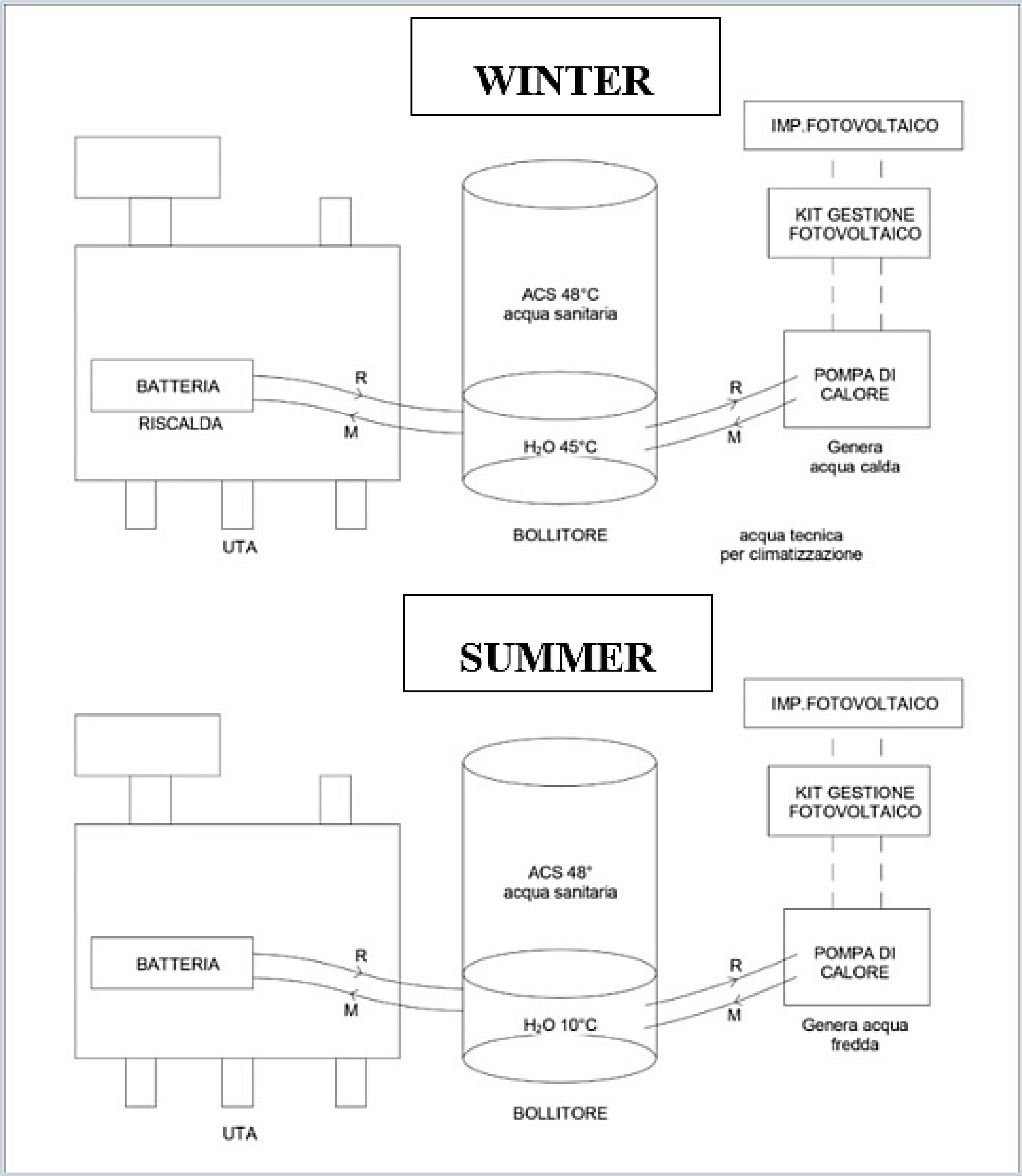


Figure 7: case study project systems scheme
Figure 8: AAL system scheme

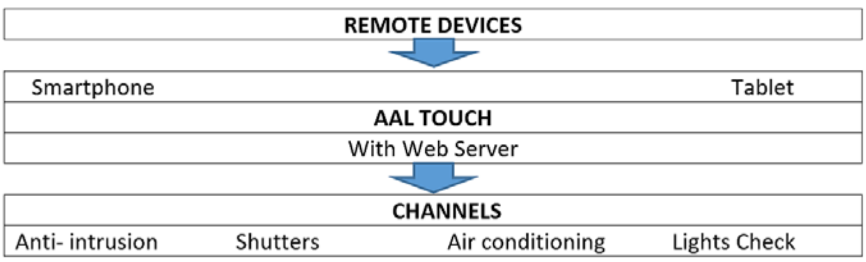
used in design between the heated and unheated rooms (between living room and garage

WALL IN BRICK AND STONE WALL

The model provides the load bearing structure in Poroton Brick, rectified, which can vary in thickness and thermal insulation in stone wool equal 10 cm. The following cases are considered: Poroton 25 + stone wool + Poroton 12, Poroton 30+ stone wool, Poroton 38, Poroton 45, Poroton 44. The potential of the brick walls without insulation was also evaluated.

THE INSTALLATIONS OF THE CASE STUDY PROJECT

The building in nZEB project is composed of the following systems: Air Treatment Unit, Heat Pump, Photovoltaic, Induction cooker, Ambient Assisted Living (AAL) Kit. The heat pump is equipped with an external monoblock, with two pipes (supply and return) connected to two accumulations (a tower of 90 lt and 300 lt) located in the technical room. The lower accumulation is the accumulation of hot / cold (water at 45 ° C in winter and at 9 ° C in summer), the upper one provides domestic hot water with a capacity of 300 lt. The lower 90lt storage tank is equipped with a circulation pump that allows hot / cold water to be sent to the ATU (Air Treatment Unit), throughout the building (first floor and ground floor). The heat pump has a capacity of 9 thermal kilowatts, i.e. 9.5 kW/ h for heating and a power of 6 kW for cooling. During the design phase it is necessary to make sure that these powers are higher than the requirements in kW of the net requirements of the systems requested by the user, as specified by the calculation software. The part of generation is therefore entrusted to the heat pump, which is equipped with 2 kettles. From there the pipes that connect to the air-conditioning terminals depart. The smaller air handling unit can process 500 m^3/h of air, the larger one can treat 1000 m^3/ h in the supply. The system scheme is shown in Figure 7.



AMBIENT ASSISTED LIVING (AAL) PROJECT

The project of the nZEB case study foresees the AAL system. It is calibrated according to user needs and aims to simplify the management of the home digitally, in order to offer a friendly service to the user. Therefore, according to the user's choices, Figure 8, the appropriate terminals will be installed. Building Automation offers the building the following functionalities:

- Video surveillance/Anti-intrusion: in order to satisfy the need for security, the AAL system can be connected to cameras and sensors placed in strategic positions of the house.
- Lighting: the AAL manages the lighting system of the house, giving the user the possibility to choose which lighting fixtures to turn on/off (ON/OFF), to choose the lighting times, and the intensity (function of dimming).
- Thermoregulation: from the AAL touch and from the remote application, it is possible to manage the temperature and humidity in each thermal zone of the building. Also in this case the on/off time can be programmed. In the thermoregulation function, meetings were held between the suppliers to understand what protocol to use in the communication between the home automation system and the air conditioning system.
- Energy saving: the management of lighting fixtures, and the air conditioning system allows for energy savings. The dimming function in particular allows the intensity of the lights to be dimmed according to the light comfort already present in natural lighting environments. Consumption is monitored by the Load Control function.
- Motorization: this feature allows automatic control of blinds, shutters, Venetian blinds, gates and windows. In most cases it can be used if users are elderly or with motor disabilities. In the case of nZEB with very high energy efficiency, the automatic motorization generates the opening/closing of certain windows to create natural ventilation whenever the ambient operating temperature exceeds the comfort temperature.
- Audio / Video: to satisfy the need for entertainment, it is possible to distribute audio and video signals.
- Since the various system components, as commonly happens in practice, come from different supplier companies, a single AAL touch has been studied, able to dialogue with all the components in order to have a single building management. For this purpose, it is possible the use of the Konnex protocol (KNX). In fact, it is the first open building automation standard, operating with an event notification logic.

CONCLUSIONS

The present work, shows how it is possible to provide the client /user with a smart tool whereby, through an online platform, starting from the definition of their needs comes to outline the future high-performance building, both functional /spatial, environmental and technological, as well as its cost. A route has been designed that the client/user can carry out independently for subsequent steps. The consequences of this approach are manifold. First of all, it contributes to making the client/user aware of the advanced technologies that will be installed in the building work, a fundamental step for the optimal use of the same during operation. Secondly, this approach helps to make the planning and execution phase shorter, thanks to the fact that much of the technological design and verification of the same has been carried out upstream, with the optimization of the process and therefore with the reduction of costs of the work against a high quality of the same. The future development of the research lies in the further implementation of this approach both in the online interface and in the interoperability of the BIM software used.

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Gianluca Di Castri

6

Planning, Scheduling and Controlling Long Term Projects

KEYWORDS: LONG TERM, PROJECT, PLANNING, CONTROLS, STOCHASTIC

The challenge that major projects face is that from design to start-up, the mega infrastructure projects can take up to 10-20 years, maybe even longer.The same applies when we need to control the whole life cycle cost of a project: in research of cost overruns, the general opinion is that these projects are out of control.

Even long term project can be duly kept under control, but we must consider the fact that controlling a short term and a long term project has a different meaning.

The paper will show how a long term project can be controlled using dynamics or stochastic methods and taking into consideration that the meaning of controls can vary according to the project characteristics and duration.

(This paper has been presented for the first time at the ICEC World Congress in Milano, 2014, and has then been revised and updated).

DEFINITIONS

This paper is relevant to long term project: we are speaking about major infrastructural projects as well as industrial project, however we shall make some references also to other, longer term projects.

Reference can be made to the study performed by the IMEC (International Program in the Management of Engineering and Construction), based on a sample of 62 projects whose average cost was 985 billion US$, the sample was composed by 15 hydroelectrical projects, 17 power plants (thermoelectric or nuclear), 6 urban transportation projects, 10 road projects including bridges and tunnels, 4 petrochemical plants.

Between the findings of the study, it resulted an average duration of 71 months for strategic phase and 49 months for executing the project, so totalling an average duration of 120 months, this is to say 10 years.

Even long term project can be duly kept under control, but we must consider the fact that controlling a short term and a long term project has a different meaning. Sometimes the owners do not really own the time span they need, in some cases the original budget are estimated lower on purpose in order to get a project decision. This has beendemonstrated for some historically important projects. Without those falsifications, we would not have St Peter in Roma nor St Paul in London, that were heavily underestimated at the beginning, it is not known whether on purpose: if the total cost were known from the beginning, nobody would make the decision to go on and the world, today, would be poorer.

On the other side, the Colosseum in Roma, whose construction lasted from year 72 to year 80, was erected quite on time and on budget.

Every project goes through a stochastic phase, where the project is still not fully defined and still is possible to cancel the project; afterwards the project becomes deterministic and, after the decision to start, it becomes quite impossible, or at least extremely expensive, to cancel it. To be fair, we should admit that no stochastic phase is fully stochastic, since there is always something deterministic and, on the other side, that no deterministic phase is fully deterministic.

The capability of the human being to foresee the future is extremely limited: most of the instruments we have only allow us to project the past data towards the future, sometimes with parametric indexes that allow for variations.

The historical data we have are generally not enough, in addition short-term statistical data and indicators are not effective when used for longer term forecasting. Furthermore, technology is evolving and this can effect long term projects, for instance due to new investments needed, increase of productiveness, variation of availability and cost of resources):

- Innovation and new technologies will change the quantity of resource needed
- Projection of data can give a quite good idea of the cost for few years
- Major political or economic events, as well as «Acts of God» or «Acts of Government» can change the project framework
- Owner related events can lead to a change of the scope of the works

It is worthy to make some consideration on the very meaning of “long term project”. In the case of a manufacturing company, normally “short term” means within the yearly cycle of the balance sheet, “medium term” means within the investment duration cycle (from 5 to 10 years, even more than 20 years for infrastructures or power generation) while “long term” means beyond the investment duration cycle). This to say that short and medium term are substantially deterministic while long term is substantially stochastic.
What about a project? It would be easy to say that a long term project is defined as a project whose duration is more than 7 or 8 years, this can be true for infrastructural projects but it is not a general definition, an IT project can be defined as a long term project if duration is more than 2 or 3 years.

We dare then to propose a new frameworks:

- **short term**: duration of activities and constraints fully defined, costs can be calculated with high reliability and a limited contingency margin
- **medium term**: constraints defined, durations can change not in a way to impact on the constraint structure
- **long term**: durations and constraints can change
- **undefined term**: besides constraints and durations, also the scope of the project can be adjusted during the project execution, sometimes there are changes in the vision of the owners and then in the goals to be achieved through the project (in this case, it would probably be better to divide the whole project in several medium term or long term minor projects and to consider all of them as part of a programme)

PLANNING AND SCHEDULING

Planning and scheduling long term projects cannot be performed with the usual methods as we use for short and medium term, this is to say that deterministic methods are not enough.

The most used deterministic method is the CPM (Critical Path Method) and its derivate such as PDM (Precedence Diagram Method) and METRA, that are fully deterministic and then not suitable for long term, sometimes planning and scheduling are only limited to work packages, that are in a further stage developed from time to time (rolling wave) as the project goes on and details become clearer, this is still a deterministic methods albeit organised into two levels and then with more possibility of being adjusted. PERT (Project Evaluation and Review Technique) is still a deterministic method, with the possibility to consider some durations with a stochastic approach.

The use of a proper, higher margin for contingencies and work variation can help up to a certain point, however it does not make any more sense if such margin becomes a substantial part of the estimated time and cost. If a project is planned to start 10 years or more, we need to use a fully stochastic planning method that allow the use of probability on constraints: even those methods would not help in case of a change in the scope of the works, that cannot neither foreseen nor controlled. Also the project framework can be modified due to owner related events or to major political events, as well as to causes normally considered as force majeure.

As far as the stochastic planning methods, as they are known in the operational research, we would like to remind:

- GAN (Generalized Activity Network), based on an equivalent network function that consider either the probability that an activity be actually performed or the change of its duration
- GERT (Graphic Evaluation Review Technique), that tries to simplify the stochastic network creating an equivalent reduced network, that can be managed as deterministic
- GERTS (GERT Simulation), that adds to GERT method the simulation
- VERT (Venture Evaluation Review Techinique), that is basically a further development of the GERTS.

In addition to those, other simulation as well as stochastic methods can be considered. In general, those methods need to be managed by experts in operational research, that is beyond the professional competence of a planner. However, some recent software initially created for deterministic scheduling allow stochastic routines and add-ons.

As far as costs are concerned, it is quite impossible to make a reliable assumption on the actual costs of a long term project if we try to make a budget adjusted through projected economic indicators, for the reason that shall be shown in the following paragraph. Useless to say, a further problem can be due to changes in the scope of the works. It is generally easier to plan the resources needed, whose amount is normally more stabilized, and then to adjust from time to time the amount of the invested money with the actual costs: this means than there is need of some flexibility in fund allocation as well as in the overall project budget.

It is enough to refer to the standards that are normally used for defining the reliability of project estimating, such as the ones from AACE International, ANSI Z94.0, ACostE, RICS (Royal Institute of Chartered Surveyors), British Petroleum, British Gas, Norwegian Project Management Association, American Society of Professional Estimators and others. If we refer, for instance, to the standards of AACE, estimating is classified into five levels whose reliability varies from -10/+15% for fully detailed project (level 1) withunit costs and bill of quantities fully known to -50/+100% for an order of magnitude estimate (level 5). Long term projects cannot be managed in a fully deterministic way, therefore cannot be considered neither in level 1 nor in level 2, while level 3 seem to be more applicable, with a -20/+30% reliability.

It is then necessary to consider that, in those cases, also budgeting becomes stochastic.

If the project starts undefined, in some cases the best way is to divide it into more subprojects out of which the first or the second are defined and, based on results of those, it would become possible to define the third, the fourth and so on. This is the case of major motorway or railway projects than can be divided in several sections to be put in operation one by one, being the other sections still not completed or even cancelled. The same has been applied to major space exploration projects such as Gemini ore Apollo; on the other side, a project like the bridge to connect Sicily to continental Italy cannot be divided into sections with the same criterion, since if only part of it is built it would become quite useless.

ECONOMIC INDICATORS

Any kind of forecast based on the value of economic indicators collected for the previous years is at risk of being completely wrong. As a matter of fact, economic indicators are normally based on a statistical analysis of a defined basket of goods, products or work processes. Those indicators are quite reliable in the short and medium term, sometimes up to 10 year time span if the procedure of data collecting and analysing is quite completed and statically correct, but they start to become unreliable if we try to utilise them for longer term economic forecast. The main reasons are:

- the basket of goods or services that are assumed as a sample has to be modified to remain statically significant, if it is not modified is at risk of losing the significance,
- the relative prices of goods and services are varying,
- the technology evolves,
- the productivity of manpower and equipment evolves too.

As an examples in year 1995 we had to calculate the equitable price for a railway maintenance workshop whose contract was stipulated on 1976 and suspended from then. The original contract value was 20 billion L.it **[1]** that, multiplied for the applicable index of 5.6, returned an updated amount of 112 billion L.it: actually this amount was claimed from contractor to complete the work. It was evident, at first sight, that such amount was extremely high, the problem we had to face was first to understand why and then to re-negotiate the contract.

When we investigated into the design, the bill of quantities and the unit prices we noticed that

- the railway signal technology used in 1976 was different from the technology of the nineties
- the price list of 1976 was still calculated considering that the rails be installed by hand, while the pricelist of the nineties was based on mechanical installation
- the productivity of electrical installation works had had a sensible increase

Our conclusion was that a fair price for the workshop should have been in the range from 54 to 60 billion L.it (useless to say, contractor should have been entitled to some compensation for having been kept waiting for twenty years, but this consideration was beyond our scope of works).

EXAMPLES

Messina bridge

The bridge to connect continental Italy to Sicily has been one of the major projects in the first decade of the XXI century; the idea to connect Sicily to continental Italy was first brought forward by the Romans, then by the King of Two Sicilies in 1840 who ordered a feasibility study. In recent time, a project based on a design of a single-span suspension bridge with a central span of 3300 m plus road and railway links was actually awarded (2005) to a consortium led by the Italian company Impregilo SpA and then abandoned (March, 2006). The budget was about 4 billion euros in 2005, in 2009 the budget was again estimated in about 6 billion euros and the project was finally cancelled for lack of funds.
It is worthy to consider that the tender documents also included for a calculation of life cycle costs over a time span of 30 years plus an additional 30 years, for a total time span of 60 years. To let understand the difficulty and limited reliability of such estimation, we have considered the projection of economic indicators from the past by using regression methods and then comparing with the actual data. Some results are shown here below:

- if we simulate a projection made in 1891, based on 30 year data base and linear regression, for a project due to last until 1921 (30 years) the actual cost for the last year is 3.74 times the estimated cost
- if we simulate a projection made in 1951, based on 90 year data base and exponential regression, for a project due to last until 2011 (60 years), the actual cost for the last year is about 35.8 times the estimated cost

The reliability of a life cycle cost calculation for so long time is based on the assumption that no major change happens neither in the world as a whole nor in the structure of the economic system. The same will apply to sensitivity analysis, that makes sense for variations of the data taken into consideration until 10% or 20%, but would be spoiled if we take into consideration 50% or 100% variations.

Petrochemical plant in Middle East

A major petrochemical plant in Middle East was composed by 13 process units centred around a steam cracker, 6 utility units and a connecting network (off-site facilities) plus auxiliary facilities such as office building, internal roads, canteen, etc. The project was actually divided into four subprojects named

- **onsite (process units)**, that were divided in section 1 (olefins, pyrolysis gasoline hydrogen) section 2 (LLD polyethylene, HD polyethylene), section 3 (polypropylene), section 4 (butadiene, polybutadiene rubber), section 5 (ethylene oxid glycol, ethanol amines, oxo gas/2 ethyl-exanol)
- **offsite** (connecting network and storage capacity),
- **utilities** (demineralization unit, cooling water system, steam generation, power generation, etc.),
- **services** (workshops, warehouses, fire stations, office building, restaurant, emergency toom, fencing, gate).

Duration scheduled for construction was about 6 years, standard workload was about 16.1 million of SMh (Standard Man-hours).

No one of those sub-projects could exist as an autonomous project, then the term sub-project was misused. The project controls was based on a project schedule and on a budget, that were verified deterministically every month, by using a PDM network, the analysis of the critical path and the usual earned value criterion to compare the planned versus the actual cost. When the project went into delay and then toregister cost overrun, although the assumption was still to use a deterministic method, the planners started to modify some constraints as well as the critical path in order to adapt the schedule to reality: this is to say that the planning became stochastic, notwithstanding the fact that such change was never declared openly. In a further stage, the owner decided to cancel part of the project to cope with previously unforeseen economic difficulties. For doing this, it was necessary to redraw the structure of subprojects since it would not make any sense to keep the process units and to cancel the utilities. Simply, the plant would not work. By this way, the scope of the project was actually modified.

It is hard to say that the project has been kept under control, but at least a default has been avoided. In reality, it would have been better to consider this possibility since the beginning, by introducing the idea of a stochastic planning and by taking into consideration a more suitable division into autonomously sustainable sub-projects.

The medieval cathedrals

One paramount example of a long term project is a medieval cathedral (according to the most used definition of the term, however, it cannot be defined as a project since time and scope were undefined).

To have an idea about how those project were managed, we can refer to a modern project that is more similar to a medieval cathedral than to the projects we are usually taking into consideration in recent times. Thisis the cathedral of the Sagrada Familia in Barcelona, whose construction started in 1882 and has not yet been completed: however the church has been consecrated by pope Benedict XVI in 2010. The original design was from the architect Francisco de Paula del Villar, then a new design was made by the architect Antoni Gaudí, involved after construction was started. Other architects were involved after Gaudí death, in order to complete his design.

Since it is an "expiatory church", like most of medieval cathedrals, construction had to rely only on private donations and therefore there was not any possibility to make a reliable planning, the work packages were scheduled from time to time according to the funds available, the progress was less that 25% in 1926 (death of Gaudí) and was estimated as 50% about in 2010. The scope of the work was changed several times, the actual design is not anymore the original one and still there are undefined points and some technical challenges. However, millions of people are visiting and it has been declared part of the UNESCO World Heritage, notwithstanding the facts that it has not yet been completed.

According to a statement from Gaudí "*El Temple Expiatori de la Sagrada Família el fa el poble i s'hi emmiralla. És una obra que està a les mans de Déu i en la voluntat del poble*" [2]

PROGRAMMES

The Messina bridge was clearly a long term project, albeit articulated in several subprojects (bridge properly so said, road connection in Sicily, road connection in Calabria), since it would not make any sense to complete the bridge without the road connections on both sides.

Different it is the case of the petrochemical complex, where the division in sections was not fully corresponding to the reality, it would have been better to consider the complex as a whole as a programme subdivided into

Project A
- process units: olefins, pyrolysis gasoline hydrogen, LLD polyethylene, HD polyethylene
- offsite (connecting network and storage capacity)
- utilities,
- services.

Project B
- Process units: polypropylene, butadiene, polybutadiene rubber

Project C
- Process units: ethylene oxid glycol. Ethanol amines, oxo gas/2 ethyl-exanol
- Additional offsite works

In reality, this is how the whole project has been managed. When the works started on project A, projects B and C were still in the strategic phase. Then, when project A was at 60% progress about project B was approved for construction while project C never started and was finally cancelled after some years.

CONCLUSION

A long term project whose scope is quite defined can still be kept under control, with proper methods, by adjusting from time to time the parametres to the actual change of the economic system as well as of the project itself.
An undefined project or programme, whose scope is not fully defined, can be kept under control section by section, if the division into sections makes sense like in the case of the railway or motorway system or of the space exploration, id est to say when every section can be considered as a quite full project. If this does not apply, like in the case of the Sagrada Familia, the very idea of controlling the project makes no sense: as a matter of fact, in 1882 was impossible to make any assumption about time and cost, thedesign was quite undefined, in reality there was only the willingness to build a cathedral. Like in medieval cathedrals, design was modified again and over again during construction, parts were added or removed, dimensions modified. Even now, that the cathedral is already consecrated (business-like, we can say that it is in operation), it is not yet clear which shall be the final design.

Note
Notes

[1] L.it = Italian Lira, the Italian currency before the Euro. The conversion ratio has been 1 € = 1936.27 L.it
[2] The expiatory church of *La Sagrada Família* is made by people and mirrors (The people). It is a work that is in the hands of God and the will of the people"

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Ugo Di Camillo

7

Multi-dimensional Risk Assessment

KEYWORDS: RISK ASSESSMENT, UNDERLYING CAUSE, ATTENTION FACTORS, SAFE SYSTEM OF WORK, PERMIT TO WORK

The International Labour Organisation has a systemic and overall approach to safe and health on workplace topics. "*5 key elements*", "*SMART outputs*", "*5 steps Risk Assessment*", are some of basic approaches suggested by this Institution. European Union has adopted this concepts to define some important procedures: "*Safe System of Work (SSW)*", "*People-Equipment-Material-Enviroment (PEME)*" and "*Permit To Work (PTW)*".
A careful analysis of accidents must be based on direct factors (primary causes) and indirect factors (secondary causes). Consequently, even a careful risk assessment must analyze and evaluate both factors, adopting a multi-dimensional approach.
The first part of the research, focused on the analysis of some indirect factors, such as ageing workers, newly hired workers, etc, introducing the concept of attention factors. In fact, these factors are not yet governed by the current national regulations within the risk assessment.
Following a systemic approach of SSW, the second part of the research is applied to a case study (construction site for a new aerospace building in Milan). Re-entering among the purposes of systematic, cyclicality and continual improvement of the measures to be taken to eliminate or reduce risks, a specific procedure has been drawn up to be associated with the scheduling and management of the site activities. Therefore, the analysis of indirect factors is performed by associating the work phase to be carried out with the employees that have these factors.
The result of the research carried out has highlighted a concept of the attention factor, which if previously assessed, can involve the activation of special worker protection procedures (e.g. Permit To Work).

INTRODUCTION

Despite the significant reduction in the number of accidents and the progress made in the field of prevention and health and safety at work, the consequences for workers are still very relevant in terms of mortality and disease. Injuries at work In Italy have caused about 11 million days of disability with costs supported by INAIL. On average 85 days for injuries that caused impairment and about 21 days in the absence of impairment. In the first five months of 2018, the fatal cases reported were 389, 14 more than in the same period of 2017.

Starting from this unrelenting perspective, the starting point of this research is based on the analysis of international regulations concerning the health and safety in the workplace, to identify areas of development and procedures that have not yet been adopted by the national one.

In fact after 25 years the adoption by Italy of the first European regulations in the field of prevention and protection of workers, many sectors have improved over time (e.g.: information and training of workers, equipment for work at height, etc.), while others have remained practically the same (e.g.: PPE, risk assessment methodology, etc.) and others never started (e.g.: procedures, organisation, health and safety management system, etc.).

The purpose of this research was to verify that some of the sectors not yet developed can effectively and substantially complete the approach to the concept of safety, ensuring greater control of the risks present. The verification was carried out by applying the tools indicated in the paragraphs following a case study of a construction site in Milan.

INTERNATIONAL AND NATIONAL REGULATORY FRAMEWORK ON HEALTH AND SAFETY AT WORK

INTERNATIONAL LABOUR ORGANISATION (ILO)

The International Labour Organization (ILO) is the United Nations agency that promotes decent and productive work in conditions of freedom, equality, safety and human dignity for men and women. The main role of the ILO is to formulate the minimum international standards of working conditions and fundamental rights of the worker. Below are just some of the many and rich concepts that can be drawn from a careful reading of the documents issued by the ILO.

Concept of primary importance is contained in the ILO Guidelines on Occupational Safety and Health Management Systems - ILO OSH 2001, following a structure that use the following five key elements, adopting the structure of Deming cycle (see Figure 1):

1. Policy (PLAN);
2. Organisation (PLAN);
3. Planning and implementation (DO);
4. Evaluation (CHECK);
5. Action to improvement (ACT).

Through these indications we can deduce the concept of system, cyclicality and continual improvement of the measures to be taken to eliminate or reduce risks in the workplace effectively. Moreover ILO C155 and ILO R164 making explicit legal requirements in regard to system of working to ensure that hazards are all identified and safe method of working are to be used, that eliminate or minimise those hazards.

Similar concepts are also found in the *5 STEPS of Risk Assessment* highlighted on ILO OSH Management System:

- STEP 1: Identify the hazards;
- STEP 2: Decide who might be harmed and how;
- STEP 3: Evaluate the risks and decide on precautions;
- STEP 4: Record your findings and implement them;
- STEP 5: Review your assessment and update if necessary.

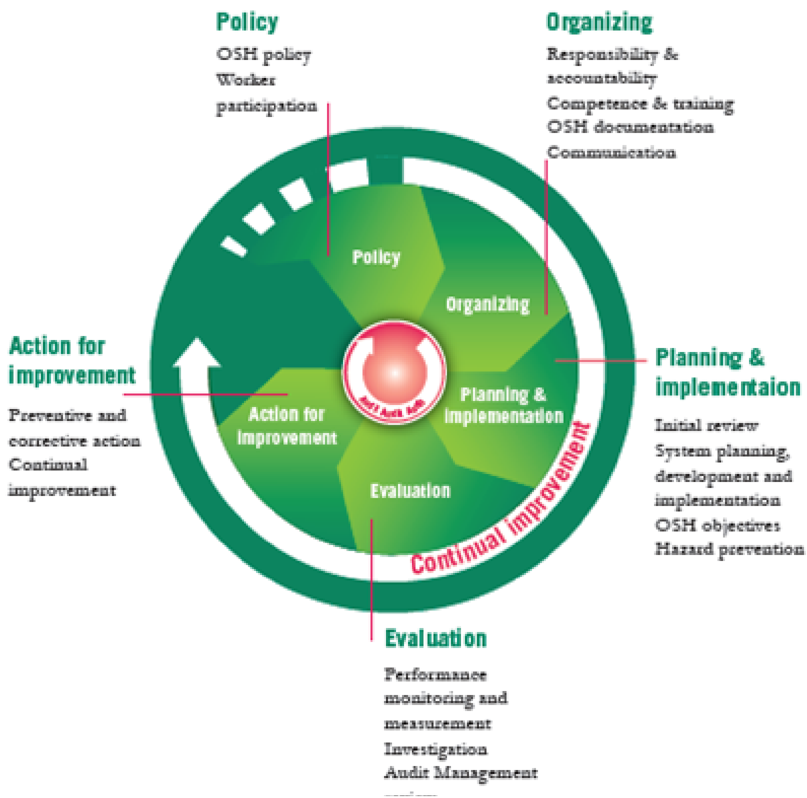


Figure 1: The continual improvement cycle (source: ILO Guidelines on OSHMS)

It is important to highlight that, unlike national regulations, STEPS 2-4-5 assume an indispensable value for a complete risk assessment.
Consequentially to STEPS 4-5 the R164 - Occupational Safety and Health Recommendation, 1981 (No. 164), is focused on the importance and relevance of written procedures. Contrary to what happens in most risk assessment documents, it does not mean that written procedures have to be complicated or difficult. As we can check in the following part (see Table 1), one of the most effective are those that are clear, and easily understood. The importance of creating written procedures is that they serve as a clear standard of works, including how the risks of the work are to be fought.

It is important that procedures express how the work is done, not just how it should be done in theory. If there is a poor match between the procedure and that can be done in practice it will devalue the procedure and others and it will cause dangerous. If a good match is achieved, in a manner that is clear to workers and supervisors, there is a higher chance that it will be complied with and the supervisors will be more able to enforce it.

"*It is important that outputs be written in an effective way. The SMART model is in line with Results-based Management (RBM) and provides a structured approach for thinking more deeply and methodically about what needs to be achieved. A SMART output is one which describes to you and anyone else what products and services you are expected to deliver within a performance cycle*". (ILO Guide to writing SMART outputs).

To achieve what is indicated in the precedent STEP 3, it is necessary to have an analytical and complete approach to the possible causes of the risk, proceeding an analysis of the injuries that have occurred in the same conditions deeper and more detailed, observing not only the direct causes but also the indirect ones. Regarding this issue the ILO Code of Practice for Recording and Notification of Occupational Accidents and Diseases 10.2 requires the Employer to, as reasonable as possible:

1. Establish what happened;
2. Determine the causes of what happened;
3. Identify measures to prevent a recurrence.

W.H. Heinrich' (1931) Domino Theory states that "*accidents result from a chain of sequential events, metaphorically like a line of dominoes falling over..*" Since the actions releted to determine the causes of an accident are often the result of many underlying or root causal failures hazards. Generally they depend by management system failures. Viceversa the immediate causes are linked to unsafe acts and-or unsafe substandard conditions. These are

OUTPUTS SHOULD BE	
Specific	State clearly and precisely what is to be delivered
Measurable	Define quality (how good), quantity (how many), time (how long), resources (how much)
Achievable	Be within resources, skills and competencies, joimtly determined, challenging
Relevant	Be linked to the unit workplan and be within your job role
Time bound	Have specific deadlines, start and finish dates

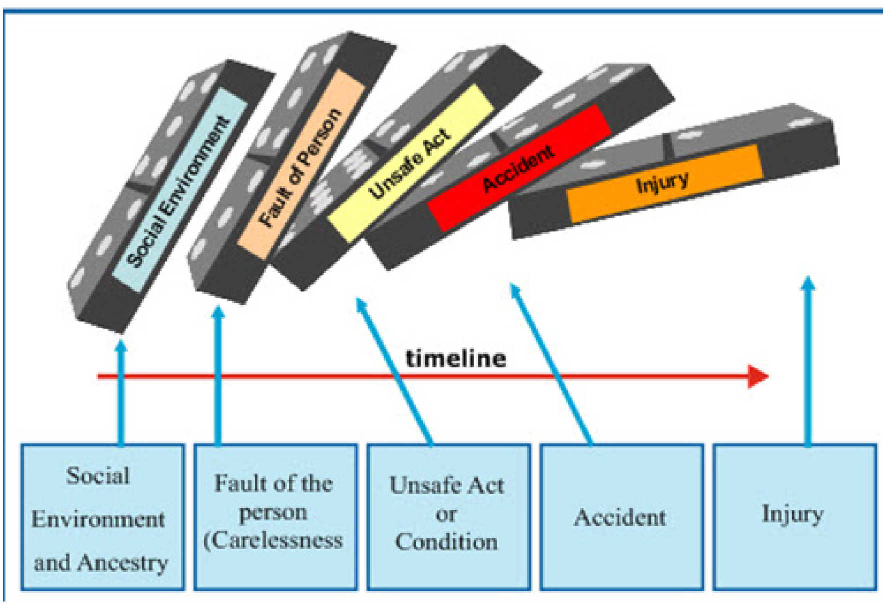


Table 1: The requirements for safety outputs (source: ILO OSH)
Figure 2: The Heinrich's Domino Model of Accident domino (source: DMI)

physical symptoms wich can be seen or sensed. Whilst these symptoms can not be ignored, only the direct preventive action at this level will not, by itself, ensure that recurrence is prevented.

European Union (OSHA)

One of the most effective ways to tackle occupational safety problems is to disseminate appropriate information to workers and employers. The European Union has therefore decided to promote this process and to create in 1996 an agency dedicated to this purpose, EU-OSHA.

EU-OSHA also pursues the very important role of identifying and anticipating possible new and emerging risks through the European Risk Observatory. In the last few years the main topics involved in the research and information work were as follows.

Aging workers.
Increasing levels of employment and prolonging working lives are important objectives of European and national policies since the end of the 1990s. The EU-28 employment rate for people aged 55-64 increased from 39.9% in 2003 to 50.1% in 2013. years in 2010 and trends in the following years are still growing faster. Work experience and skills accumulate with age. However, some functional abilities, mainly physical and sensory, decrease due to the natural aging process. Changes in functional capabilities due to age are not uniform as there are individual differences in terms of lifestyle, nutrition, fitness, etc. In some studies, the Work Ability Index parameter began to be evaluated, linked to the ability to support working conditions that can cause physical and psychological stress in workers aged between 50 and 70 years. Risks related to aging workers include in particular:

- heavy physical work;
- hazards related to shift work;
- work in noisy environments or in low or high temperature conditions.

Young workers and newly hired
Statistics show that people aged 18 to 24 are more likely than other adults to suffer a serious injury at work. They may be exposed to poor working conditions that result in the development of occupational diseases when they are still young or later. Being unfamiliar with the workplace, young people do not have experience and are often still immature, both physically and psychologically, as well as not taking the risks they face seriously enough. In an emergency situation they do not have adequate knowledge to effectively deal with the present danger.

Safe System of Work (SSW)
Several European national regulations have acquired from the Guidelines ILO the concepts of "*safe person + safe place + safe system = Safe System of Work*" (e.g. "*clean up after you do work*"). Those are working methods resulting from an assessment of the risks inherent in a task, and identification of the precaution that are needed to do that task in a safe and a healthy manner. It is very important to highlight that a Safe System of Work is an integration of: People, Equipment, Materials in the correct Environment to ensure health and safety (PEME).

"*A system of work is a set of procedures according to which work must be carried out. Safe systems of work are required where hazards cannot be eliminated and some risk still exists. When developing your safe systems of work, consider how the work is carried out and the difficulties that might arise and expose you or your workers to risk. Then develop a set of procedures detailing how the work must be carried out to minimise or reduce the risk of accident or injury.*" (Ireland Health and Safety Authority).

Italian legislation (D. Lgs. 81/08)

The first reference in Italy regarding the legislation on safety at work is the Legislative Decree 81/08, for all often simply called the "*Testo Unico sulla Sicurezza*" (TUS), that has been elaborated in compliance with the philosophy of the community directives focused on the planning and participation of all the subjects involved in the work.

Recently some innovative elements introduced by TUS have concerned the obligation for the employer, to assess among the risks also those related to work-related stress, to pregnant workers, to differences in gender, age of workers and their origin from other countries. With regard to the management systems, these regulations recall the national ones: SGSL 28/09/2001, European: BS-OHSAS 18001/2007, or international (UNI EN ISO 9000:2001). It should be noted that their application in the construction field sector is still rather limited.

RISK ASSESSMENT: DIRECT AND INDIRECT CAUSES

Two-dimensional risk assessment

the number of risks taken into consideration may also vary substantially depending on the field of application, the nature of the work, the complexity of the work, etc. However, in general it is possible to identify and classify risks related according to the following categories of hazards (regardless of the interferential ones):

- Workplace hazards;
- Work equipment hazards;
- Electricity at work;
- Chemical and biological health hazards;
- Fire and explosive substances;
- Physical and psychological health hazards;
- Muscoloskeletal hazards.

In construction site field, the risk analysis is normally focused on mainly on the main most frequent causes of accidents, in particular:

- Working at height (hazards: workplace – equipment);

- Falling materials (hazards: workplace – equipment);
- Collisions with vehicles (hazards: workplace – mobile work equipment);
- Mechanical and machinery contacts (hazards: machinery – equipment – engine tools);
- Electrocution (hazards: mobile work equipment – equipment – plant - electrical tools).

Risk assessment, according to a traditional approach, results in a two-dimensional type: frequency and entity (see Table 2). Consequently, the preventive and protective measures necessary to eliminate and reduce the assessed risks are concentrated towards the higher level risks (prioritization of risk).

The analysis of possible causes adheres to direct and immediate factors, therefore the proposed solution will belong to protective nature and will mainly be technical-engineering (e.g.: risk of falling from high = protective measure = inserting the guardrail), consistent with the analysis of the direct causes connected to an eventual accident (risk falling from high = direct cause of lack of guardrail).

Multi-dimensional risk assessment

As indicated by ILO-OSHA, the multi-dimensional risk analysis must deal with the concept of systematicity of the approach and therefore extend its horizons to factors that are not adequately taken into consideration, such as:

- identification of the people at risk, who might be harmed and how (e.g.: vulnerable people, young workers, aging workers, etc.);
- work organisation (e.g.: lone workers, night shift, weather conditions, etc.);

moreover those that belong to traditional risk assessment:

- job or task factor (e.g.: technical equipments, PPE, etc.).

This concept is closely correlated with analysis of underlying causes of accidents/ incidents. Identifying the underlying root causes will explain why the substandard act happened or the conditions arose. They are not always easy to identify. Generally indirect causes fall into three major categories:

- personal factors (e.g.: attitude, physical capability, skill, etc.);
- organisational factors (e.g.: procedures, communication, etc.);
- job factors (e.g.: design of equipment and layout, environment, etc.).

In this situation risk control measures must appeal to technical-engineering part (e.g.; falls from high = protective measure = to install guardrail), both organisation-procedural part (e.g.: falls from high = preventive measure = work off with snow and ice on path), and lastly to individual-behavioural part (e.g.: falls from high = preventive measure = allowed only expert and healthy workers).

In this research as a first step, a document is designed that could analyze risk factors that derive from underlying causes to enable a choice of the most effective security measures. The criteria with which it was conceived, however, followed the outputs provided by the PEME concepts.
It was deemed appropriate not to quantify such risks, since there was no adequate case study to measure their frequency and severity and also it would not be possible to determine the weight to be attributed to the different categories. It was therefore decided to address these risks by carrying out an analysis and possibly verifying their presence in the planning phase of the workings. For this reason they have been identified with the term "attention factors", as their possible presence must contribute to increase the attention

			PROBABILITA'				
			Sicuro	Probabile	Possibile	Remota	Improbabile
			5	4	3	2	1
EFFETTO	Mortale	5	25	20	15	10	5
	Grave	4	20	16	12	8	4
	Media	3	15	12	9	6	3
	Bassa	2	10	8	6	4	2
	Minima	1	5	4	3	2	1

Classificazione rischio: **Basso**	**1 - 8**	**verde**
Classificazione rischio: **Medio**	**9 - 15**	**arancione**
Classificazione rischio: **Alto**	**16 - 25**	**rosso**

Table 2: A typical two-dimensional risk assessment (source: THEMA)

towards the choice of additional and complementary organizational and individual measures to those already identified for processing.

Therefore from this scenario, a check list (see Table 3) has emerged that summarizes some of these attention factors, associated with each individual process, conforming to EU-OSHA, such as:

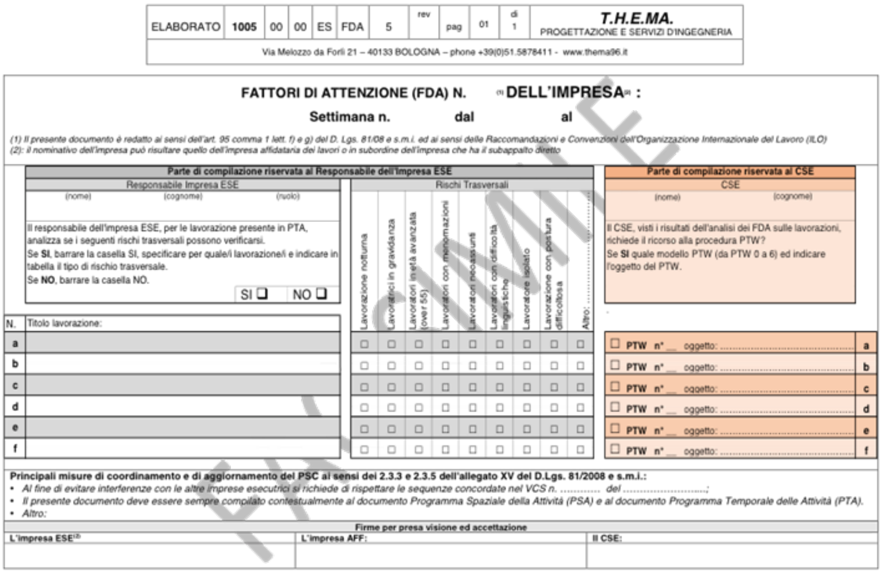
- night job;
- pregnant workers;
- elderly workers (over 55 years);
- newly hired workers;
- workers with linguistic difficulties;
- lone workers

Their possible presence must induce the site's managers to take appropriate supplementary measures, such as the adoption of the Permit To Work procedure. In the case study, this procedure will be further investigated.

APPLICATION OF SSW PROCEDURE: STUDY CASE

The case study is based on the realization of an industrial expansion site in Milan. The Private Client deals with the production and implementation of equipment and tools for the aerospace sector. In particular, the Client had set the goal of concluding the works after only 6 months from the beginning of the construction site, as he had to have the next satellite assembled inside the new expansion denominated "clean room".

This deadline for the mandatory and imminent work involved an extremely detailed and precise planning and a careful and constant project management, especially with regard to the progress of the work. In this context, the aspects related to the health and safety of the workers of the construction site, depending of the adjacent offices of the Client and the intersections between the traffic of the construction site and the neighboring Via Gallarate, were



ELABORATO	1005	00	00	ES	FDA	5	rev	pag	01	di 1	T.H.E.MA. PROGETTAZIONE E SERVIZI D'INGEGNERIA

Via Melozzo da Forlì 21 – 40133 BOLOGNA – phone +39(0)51.5878411 - www.thema96.it

FATTORI DI ATTENZIONE (FDA) N. (1) DELL'IMPRESA(2) :

Settimana n. dal al

(1) Il presente documento è redatto ai sensi dell'art. 95 comma 1 lett. f) e g) del D. Lgs. 81/08 e s.m.i. ed ai sensi delle Raccomandazioni e Convenzioni dell'Organizzazione Internazionale del Lavoro (ILO)
(2): il nominativo dell'impresa può risultare quello dell'impresa affidataria dei lavori o in subordine dell'impresa che ha il subappalto diretto

Parte di compilazione riservata al Responsabile dell'Impresa ESE

Responsabile Impresa ESE
(nome) (cognome) (ruolo)

Il responsabile dell'impresa ESE, per le lavorazione presente in PTA, analizza se i seguenti rischi trasversali possono verificarsi.
Se **SI**, barrare la casella SI, specificare per quale/i lavorazione/i e indicare in tabella il tipo di rischio trasversale.
Se **NO**, barrare la casella NO.
SI ☐ NO ☐

Parte di compilazione riservata al CSE

CSE
(nome) (cognome)

Il CSE, visti i risultati dell'analisi dei FDA sulle lavorazioni, richiede il ricorso alla procedura PTW?
Se **SI** quale modello PTW (da PTW 0 a 6) ed indicare l'oggetto del PTW.

N.	Titolo lavorazione:	Lavorazione notturna	Lavoratrici in gravidanza	Lavoratori in età avanzata (over 55)	Lavoratori con menomazioni	Lavoratori neoassunti	Lavoratori con difficoltà linguistiche	Lavoratore isolato	Lavorazione con postura difficoltosa	Altro:		
a		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐ **PTW n° __ oggetto:**	a
b		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐ **PTW n° __ oggetto:**	b
c		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐ **PTW n° __ oggetto:**	c
d		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐ **PTW n° __ oggetto:**	d
e		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐ **PTW n° __ oggetto:**	e
f		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐ **PTW n° __ oggetto:**	f

Principali misure di coordinamento e di aggiornamento del PSC ai sensi dei 2.3.3 e 2.3.5 dell'allegato XV del D.Lgs. 81/2008 e s.m.i.:
- *Al fine di evitare interferenze con le altre imprese esecutrici si richiede di rispettare le sequenze concordate nel VCS n. .... del ....;*
- *Il presente documento deve essere sempre compilato contestualmente al documento Programma Spaziale della Attività (PSA) e al documento Programma Temporale delle Attività (PTA).*
- *Altro:*

Firme per presa visione ed accettazione

L'impresa ESE(2)	L'impresa AFF:	Il CSE:

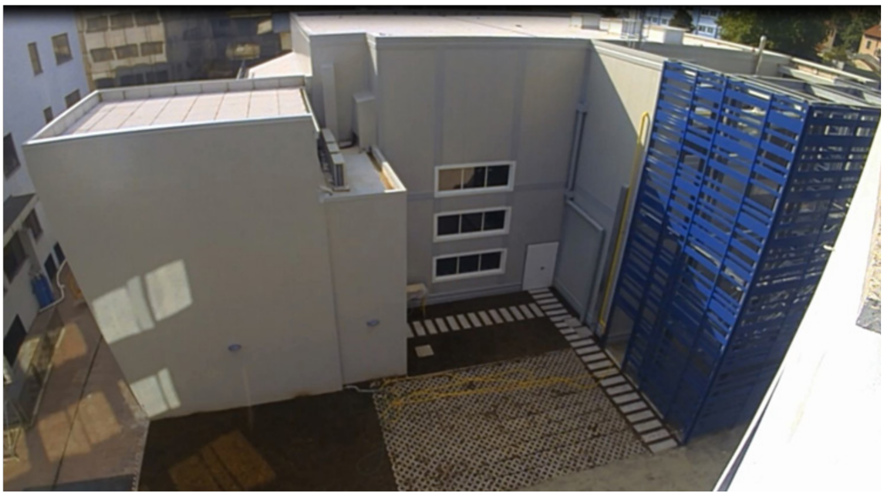


Table 3: Attention factors check list (source: THEMA)
Figure 3: Rendering of the new building (source: THEMA)

among the key factors to be managed to avoid dangerous repercussions on the expected result.

Therefore it is not surprising that the Client has shared with the designers the opportunity to use additional security procedures compared to those established by current regulations, to protect both workers and the achievement of the temporal objective.

Description of the intervention

The intervention that has been carried out has the following characteristics:

- Location: *Milano Via Gallarate, Via Bressanone e Viale del Ghisallo*;
- Client: *OHB Italia SpA - Milano*;
- Design, project management, HSE consultant: *THEMA srl – Bologna*;
- Type of intervention: *new building intended for the production and implementation of equipment and tools for the aerospace sector*;
- Dimension of intervention: *circa 1.000 m²;*
- Cost of intervention: *circa € 3 million;*
- Duration of construction site: *6 months.*

Development of a Safe System of Work (SSW)

The second step of the research has concerned the development of SSW mainly followed the principles and guidelines found in the initial chapter, adapting them to national regulatory requirements. The criteria with which it was conceived, however, followed the outputs provided by the Deming cycle concepts.

Therefore, the development of the SSW has gone through a systematic, cyclic and dynamic approach that involves the direct managers involved in the workings, according to the following main steps (see Figure 4):

1. Before the Construction site starts (PLAN): the Safety and Coordination Plan (SCP) contract document indicates the procedures to be

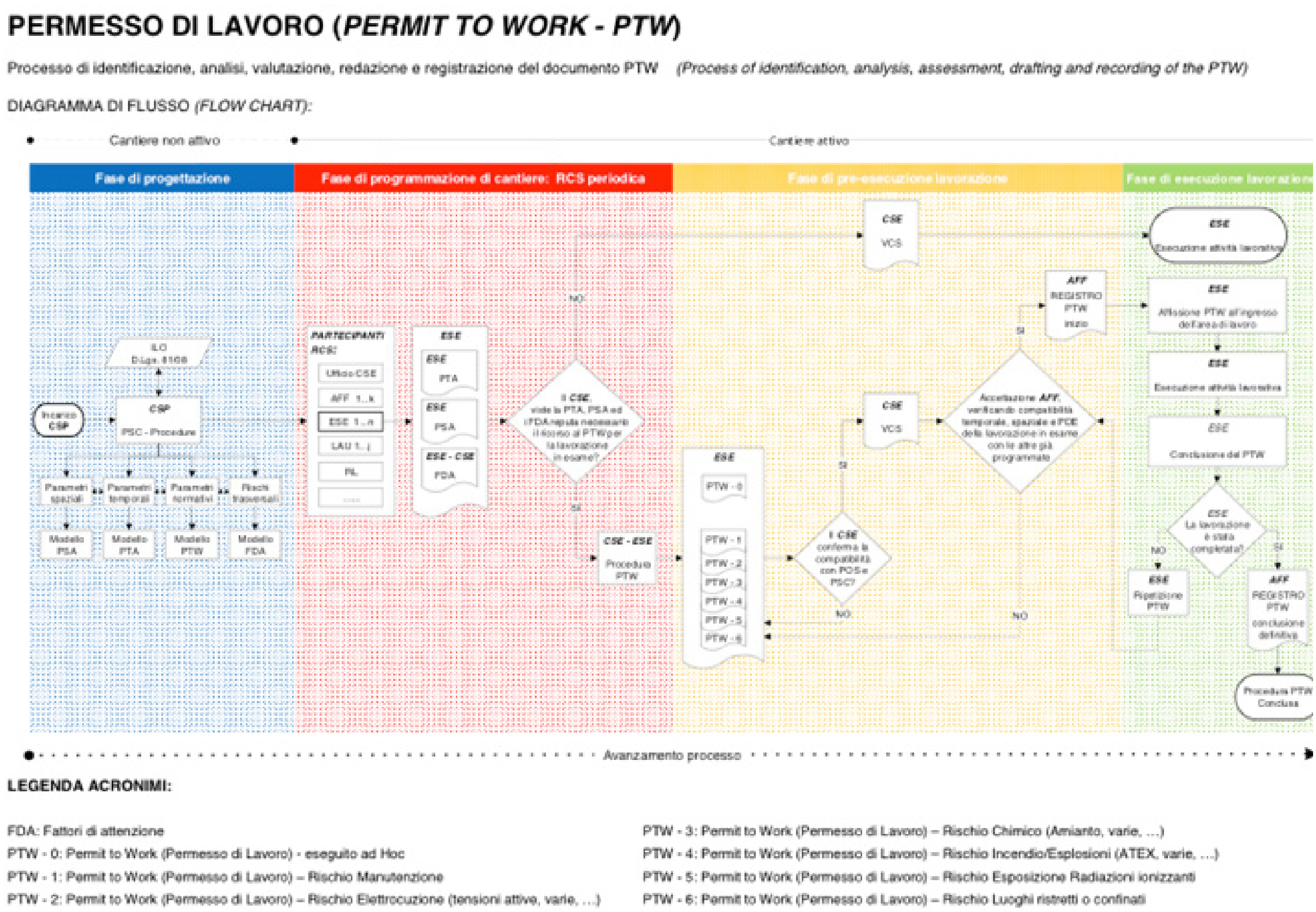


Figure 4: Flow chart of SSW for the remarkable risks on construction site and PTW procedure (source: THEMA)

followed for the analysis, evaluation and adoption of preventive and protective measures relating to all the risks envisaged in the construction site;

2. After the Construction site started:
   a. Planning phase of construction site work (DO): following the procedures indicated in the SCP, the site managers perform the spatial and temporal planning of the activities analyzing, evaluating and adopting the preventive and protective measures relating to all the risks foreseen in the construction site;
   b. Pre-execution phase of work on construction site (CHECK): on the basis of the assessments carried out, a Permit To Work (PTW) procedure is eventually activated;
   c. Phase of execution of workings (ACT): the agreed and envisaged procedures in the SCP are adopted and applied to eliminate and / or reduce the foreseen risks. Any anomalies and / or repetitions of the procedure are analyzed.

The main features of this SSW have been designed with the aim of fulfilling the fundamental principles of sequential, cyclic and dynamic steps.

Permit To Work procedure (PTW)

The third step of research concerned the activation of the SSW in the SCP that was foreseen in the following possible cases, to be evaluated during the works:

1. Maintenance of plant and-or roof;
2. Work on plant with live electrical power;
3. Use of chemical substances and-or dangerous products (e.g. asbestos);
4. Fire and-or explosives substances;
5. Ionizing radiation;
6. Confined spaces.

while it was mandatory for the following work:

7. Working at height during the assembly of new roof .

In fact, in the SCP one of the most intrinsically dangerous working phases was the one related to the assembly of the roofs of the new building. The main risks were those that can be attributed to the fall from heigh of workers and objects. To prevent them it was vital that SSW should be in place.

Coherently with the considerations previously made, as an integrative tool that was considered to be included in the project phases, the use of the procedure called Permit To Work (PTW) was envisaged. This procedure, already widely used in industrial areas (eg chemical industry, oil industry, etc.), is rarely applied in the construction site world. On September 29th 2017 it was then included in the tender documents within the SCP document, just to point out the cogency in terms of security and mandatory nature for the general contractor and the sub contractors involved.

Generally the PTW is a written document that authorizes some workers to carry out specific work, in a specific period of time in a specific work place and through the activation of appropriate preventive safety measures. The PTW adopted in the this construction site was a unique tool in the numerous documents on the site, in fact some of its features have distinguished it completely from the rest of the others. The criteria with which it was conceived, however, followed the outputs provided by the SMART concepts:

- It needs to fill in different parts of the template to respond to the following questions (Smart: Specific outputs):
  - WHO are the responsible?
  - WHAT do actions need to be taken?
  - WHEN shall the actions be executed?
  - HOW shall the responsible act?
- It needs to compare it with others important documents (e.g.: SCP) and to check the quality and quantity of safety arrangements specified (sMart: Measurable);
- The outputs challenging are within the competences and skills of "actors" included in the list. If not, it is predictable a specific Induction Training. The time frame proposed can be delivered. (smArt: Achievable);
- All the responsible shall sign in the template. The document has a relevant value inside the SCP and SSW procedures. The PTW shall exposed outside the workplace (smaRt: Relevant);
- Outputs shall have a specific time frame and deadline. If it needs an extra time deadline they are defined the key steps to reviewing the procedure (smarT: Time bound).

What is highlighted during the meeting with the direct responsible of works is that a PTW is not simply permission to carry out a dangerous job. It is an essential part of a system which determines how that job shall be carried out safely. The permit should not be regarded as a statement that all hazards and risks have been eliminated from the work area. The issue of a permit does not, by itself, make a job safe. The PTW system should ensure that only authorised and properly trained people have thought about foreseeable risks and that these are avoided by using suitable precautions. Those carrying out the job should think about and understand what they are doing and how their work may interface with that of others. They must also take the necessary precautions which they have been trained to take and for which they have been made responsible.

It was considered important to reiterate that for the actual operation of the PTW it is necessary that this instrument be used only for particularly critical conditions. If applied widely and for standard conditions it is likely that:

- it is not regularly applied, because it unjustifiably slows down the work involved;
- be underestimated by the workers

PERMESSO DI LAVORO (Permit To Work - PTW) N. 004

Cantiere: ARCOBALENO & CO - Ampliamento PAD. 203	Impresa AFF: FLAVIO VERDI e FIGLI S.a.s.
Oggetto PTW: LAVORAZIONE IN QUOTA: POSA IN OPERA DI LAMIERA GRECATA	

ai sensi del D. Lgs. 09 aprile 2008 n. 81 (e s.m.i.)
ai sensi delle Raccomandazioni e Convenzioni dell'Organizzazione Internazionale del Lavoro (ILO)

Tutti i 9 punti della fase di pre-esecuzione della lavorazione devono essere compilati per intero, prima che l'attività lavorativa abbia inizio.

Fase di pre-esecuzione lavorazione

1. RESPONSABILE DELL' IMPRESA ESE

Impresa ESE	(nome)	(cognome)
MARTINELLI LAMIERE S.r.l.	PIERO	LAME
	(ruolo)	(telefono)
	PREPOSTO	310 000 0000
	(firma) Piero Lame	

2. VALIDITA'SPAZIALE E TEMPORALE PTW

Descrizione dei lavori (dove, cosa, come): *Fornitura e posa in opera di lamiera grecata nella copertura del PAD. 203.*

AREA DI LAVORO: PADIGLIONE 203 - COPERTURA

PTW VALIDO DA: (INIZIO)		PTW VALIDO A: (CONCLUSIONE prevista)	
(data)	(ora)	(data)	(ora)
25 / 11 / 2017	08:00	25 / 11 / 2017	19:00

3. FATTORI AMBIENTALI

Nel caso si presentino i seguenti fattori ambientali è **obbligo non iniziare** o **sospendere** la lavorazione.

	SI	NO
Pioggia / Neve	X	
Piano di lavoro bagnato o umido	X	
Materiali accatastati		X
Illuminazione artificiale	X	
Altri:		

4. IMPIANTI TECNICI

I seguenti impianti tecnici saranno **isolati** e **bloccati** per l'intera durata della lavorazione:

	SI	NO
Rilevatore di fumo / gas	X	
Rilevatore antincendio		X
☐ Serbatoi ☐ Condotti ☐ Valvole		X
☐ Dispositivi ☐ Prese elettriche		X
Altri:		

5. MISURE DI SICUREZZA PREVENTIVE

Le seguenti misure di sicurezza saranno attuate **precedentemente** e **durante** la lavorazione:

	SI	NO
Specifici per la Gestione delle Emergenze (Cfr. PdE)	X	
Segnaletica di pericolo	X	
Parapetti provvisori	X	
Rimozione materiali pericolosi	X	
Rete anticaduta		X
Altri:		

6. ATTREZZATURE E DPI

Le seguenti attrezzature ed i seguenti DPI saranno utilizzate **durante** il corso della lavorazione:

	SI	NO
Specifici per la Gestione delle Emergenze (Cfr. PdE)	X	
Dispositivo UNI EN 353	X	
Dispositivo UNI EN 363	X	
☒ Scala telescopica ☒ Scala a pioli		X
PLE	X	
Scarpe antinfortunistiche	X	
Linea Vita	X	
☒ Funi ☒ Imbracatura	X	
Cascetto con sottogola	X	
Dissipatore di energia	X	
Altri:		

Pagina 1 di 2

Table 4: Permit To Work filled in (source: THEMA)

and therefore be followed without due attention.

Also for this reason, a specific PTW Register has been compiled, where all the most relevant PTW data in progress and / or completed are recorded in chronological order.
It is in any event essential that anybody starting work is familiar with the local instructions detailing when and how PTW systems are to be applied at a particular location. A specific information-instruction-training session should be done and registered in appropriate format denominated Induction Training.

The format adopted on the construction site (see Table 4) was designed with the logic of responding to the requirements indicated above, but also to respond to the specific peculiarities of the national legislation. In particular, it was considered indispensable that the PTW involved besides the contractor also:

- Safety Coordinator during Construction phase (SCC): as a subject implementing the SCP and validator of the Method Statement, but also responsible for verifying any interference between workers on site. For these reasons it was considered necessary to assign the PTW validation role to the SCC;
- General Contractor (GC): as a company for the overall management of the site and coordinator of all the work to be done. For these reasons it was considered necessary to assign the role of acceptance of the PTW.

Furthermore, among the peculiarities identified in the use of the PTW it has emerged to avoid dangerous interferences or poor management during the passage of delivery of the work areas between different contractors. This will apply equally when there is a transfer of work and responsibilities from one group to another.
The next step of the research, will be that of being able to proceed to multi-dimensional risk evaluation according to parameters comparable with those of traditional two-dimensional risk analysis. This step would allow a comparison between the different risk classes and thus lead to a more comprehensive and overall view of the risk assessment concept (see Figure 5).

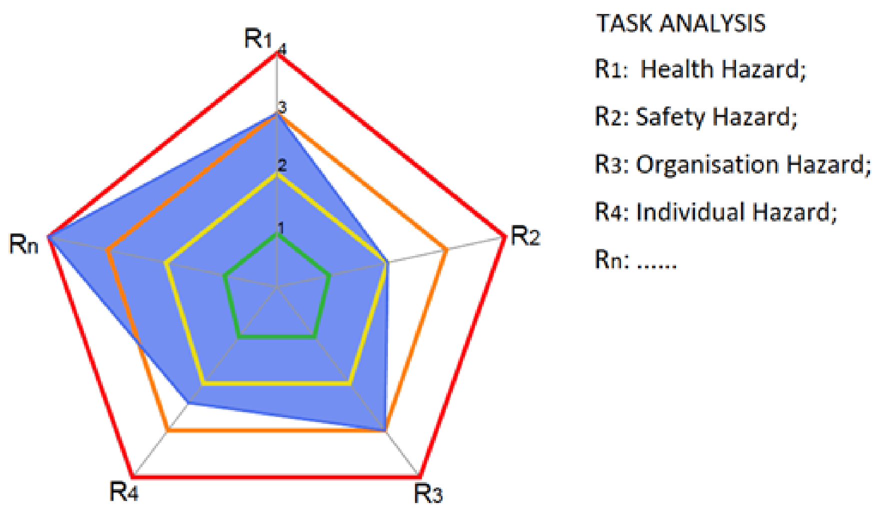


Figure 5: Possible scheme of multi-dimensional risk assessment (source: THEMA)

CONCLUSIONS

The approach used to address the case study has shown the usefulness of adopting procedures referred to by international regulations. In this scenario a multi-dimensional risk assessment could finds out a correct context.

It should be noted that the compilation of the PTW, in the cases envisaged by the SCP, did not encounter major obstacles by the companies involved, since its drafting was generally carried out during the weekly meeting of the construction site and therefore in a well-prepared area for the planning of activities and the assessment of related risks. This aspect also facilitated the collection of signatures of the various managers and the exchange of information with the workers involved.

Minor results were instead made in the application area of the PTW during the work phases involved, as the contractors have not always managed to respect some factors considered indispensable for its application, for example:

- No turnover of designated workers;
- Observance of time scheduling;
- Observance on PPE and signs;
- Delivery of workplaces in safety and proper conditions.

The compilation of attention factors record did not entail great difficulties by the contractor involved. Despite a first attitude of curiosity and surprise towards its compilation (moreover for the identification of worker over 55), this tool became more familiar to the various managers involved.

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Serena Di Marco

8

Construction Site Planning for the Reconstruction of a Historic Earthquake City: the Case Study of L'aquila

KEYWORDS: EARTHQUAKE, L'AQUILA, RECONSTRUCTION, CONSTRUCTION SITE PLANNING, EARTHQUAKE OLD TOWN

The earthquake that hit the city of L'Aquila on 6th April 2009 represents the first seismic event, after that of Messina in 1908, that interested such a wide and urbanized area as that of a county seat. Emerged problems after this occurrence, the mistakes that have been made and the set of adopted solutions, made L'Aquila to become a real "knowledge laboratory".
In this context, the attention focuses on the complex issue of L'Aquila old town reconstruction, often defined by the most important newspapers as "the biggest construction site of Europe". Once have analyzed the procedures that the city council put in place, it is observed an absence of an instrument of planning through which to coordinate the construction sites simultaneously operating on the area. The first to deal with this problem has been the municipality of Villa Sant'Angelo, that through the drafting of a "general construction site plan", attempted to manage the critical issues about reconstruction. Starting from this cue, an elaboration of a general construction site plan is proposed for the "central axis" of L'Aquila old town. The goal is to plan construction site activities on the base of strategic choices followed from L'Aquila old town conditions after the earthquake, by referring to an urban scale instead of considering individually each single construction site. Awork plan is obtained throughthe definition of requirements concerning the priority criteria for action, the old town viability, the logistics of construction sites and the rubbledisposal. This plan fosters a more functional and safer reconstruction, and a fairer use of public spaces from companies which execute private works.
Therefore, by using as starting point the implementation of the method in the case study of L'Aquila, it is here proposed an application solution concerning the management of reconstruction of Italian old towns hit by earthquakes.

INTRODUCTION

Italy is one of the countries in the Mediterranean area which has got higher seismic risk, because of both thefrequency of the earthquakes that hit the country throughout history, and for their magnitude. The earthquake that hit the city of L'Aquila on 6th April 2009 generated a so-called seismic crater that comprises 56 municipalitiesandconcernsan area ofalmost 2.400 Km². In light of this, the reconstruction process of L'Aquila has been soon defined as "the biggest construction site of Europe". Because of the particularly complexsituation, the seismic crates became a real "knowledge laboratory". This experience, in fact, reignited in everyone the sense of importance of seismic prevention in Italy, and let also to implement new models and techniques of intervention both in the emergency phase and in that of reconstruction.

In an old town that has been hit by an earthquake, there are two typologies of after-earthquake construction site. A first typology is the one concerning the moment immediately after the emergencyandthatincludesconstruction sites for compellinginterventionof safety works. The second typology refers to building sites for reconstruction. Those operate by following the rules laid down in theUniform Codeof Health and Safetyat Work, butdisplay more complex scenarios in comparison with a commonbuilding site, due to the presenceofvarious risk factors. It is clear that for a construction site of an old town

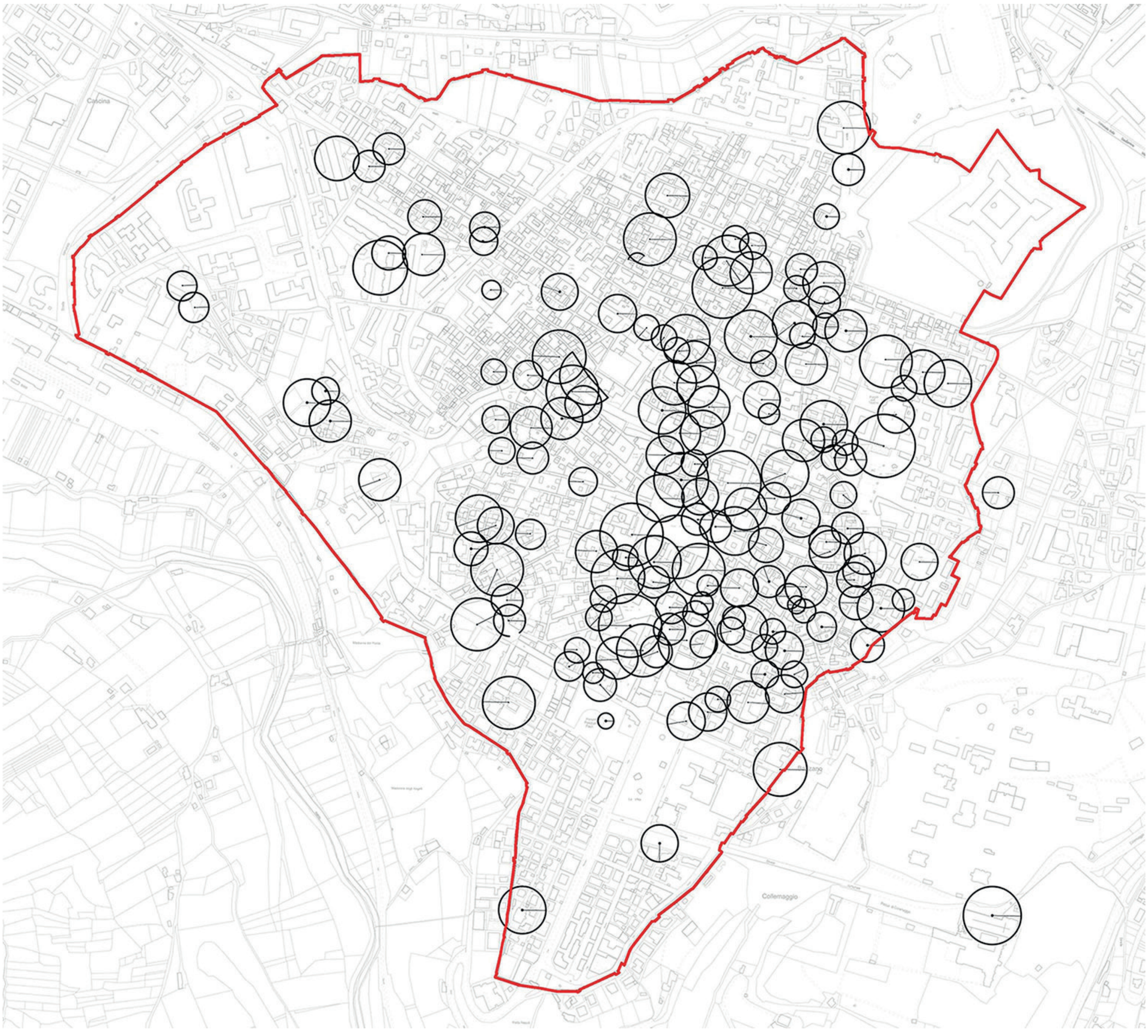


Figure 1: Plan of the active cranes encumbrance in the old town of L'Aquila, October 2017

reconstruction it is necessary to foresee very specialplanning and organization features, that aim to obtainaflexible and complex structure, articulated on the base of the nature of the existing one. The main problemsthat can be observed in this field concernin particular: the management of public spacesby many construction sites, the existence of impactfulemergency structures and areduced viability with a subsequent reduction of room for means maneuver. Despite these are problemsconcerning in particular executing companies of private works,it is necessarythat the city council manages and leads the reconstruction throughthe action planning on a urban scale. What has been missing in L'Aquila has been the cooperationbetweenpublic and private spheres;this brought to a non-plannedand, consequently, non-homogeneous reconstruction. In light of this, it has been developed ageneral construction site planfor the old town of L'Aquila,which provides the guidelines for implementinga more functional and coordinatedreconstruction. The main objective of the plan it will be to develop a logical approach to design and organize the reconstruction site on an extensive area. The development of the general construction site plan for the case of L'Aquila represents the starting point for having the tools to better understand the problem of the reconstruction site management. In this way, it will be possible to apply this method, not only for the territories hit by the earthquake but also for those affected by other disasters due to natural hazards (e.g. floods, tsunamis, landslides, etc.).

THE RECONSTRUCTION OF L'AQUILA OLD TOWN

The Reconstruction Plan

Theapproachadoptedby theMunicipality of L'Aquila for reconstruction activities is based oncontents of the extraordinary legislation on reconstruction, issued by the Government and the Commissioner-Delegate; those are the Law n. 77 of 24th June 2009 and the Decree n. 3 of 9th March 2010, respectively. In particular, thelaw 77/2009 introduces againtheReconstruction Planas an instrument ofurban planning by settingits aims, including: the socio-economic recovery of thecity, the upgrading of the housing stockand the returnof people into the houses damaged by the earthquake. TheReconstruction Planis defined as technical instrument, which unifies more "levels of planning" asthestrategic plan, the generalurban equipmentand the implementing planning. Those arecomprised in a single and articulate planning programmingprocess.

The above-mentioned decreesets goals and procedures for the drafting of the Reconstruction Plan. In particular, with a view to the arrangement of thestrategic guidelines for old towns reconstruction, the Municipality of L'Aquila defined theboundaries of eachold town in the county seat and in the hamlets, byidentifyingreconstruction settings. Into those settings, it is forecasted the presentation and the following checkof intervention proposalsafterpublic notices issued by the Mayor. This approach favors the current urbanand territorial prefiguration,while pursuing the direct and freerecovery and consolidation measures of damaged buildings; this is made throughthe possibilitytoproceed with the reconstruction by usingproposing plans,made bysingle areas or sections of areas, in conformity withthe current Land-use planning. By following this line of action,theold town reconstructionhas been left to chance,to the individual initiative and without an overview of the city. For all those reasons, the reconstruction plan turns out to be an ineffective instrumentfor managing the reconstruction of L'Aquila.

The office for the super-coordination of construction sites

With the Protocol of Understanding called Emergenzasisma Abruzzo 2009, of 30th November 2009, ithas been agreed on the necessity to optimizeand safely managethe multitude of temporary or mobile construction sitesin the old town of L'Aquila, during the phase of the buildings securing. It has been set up the Office for the Super-Coordination of Safety in Construction Sites. In the same protocolit has been considered, moreover, the extensionof the officetasksalso during the reconstruction phase. The Office for Coordinationrepresentsa supportfor the municipal Administrationand is mainlycommitted to the control of eachSafetyCoordinator's tasksrelatively to provisions and requirements aimed to the respect of the current regulation on safety in work places. During the phaseof L'Aquila old town reconstruction, the main activities of the office concernthe definition of the safety and health requirements for the logistic of construction sitesand the requirements for the behavior of Safety Coordinators (in the phases of projecting and implementing) and of executing companies. In particular,techniciansof USC complement the Coordinators during the phase of implementingthe activitiesrelated withthe logistic of construction sites' common areasand the managingof interferencesamong many processing,by organizing periodic meetingsof construction sites coordinationand by encouraging training meetingsin order to make known all the issues concerning the risks in the construction sites for reconstruction. Although this represents a key aspectin the field of a such complex reconstruction,the office for the coordination of construction sitesdrafts guidelines limited only to the issueof safety in the construction sites and to the controlofregularityof workersduring the operative phase of the construction sites.

The general construction site plan of Villa Sant'Angelo

By analyzingthe difficultdevelopmentof reconstruction of L'Aquila old town, it results essential the contribution given by the municipality of Villa Sant'Angelo (AQ),with the development of theGeneral

Construction Site Plan of its old town and od the hamlet Tussillo. The project starts with the goal to meet the requirements of companies that are going towork simultaneously in the hamlet old town, in order to let them avoid, for example, problemsin the implementing phase of the construction site, related to a wrong positioning of the crane form a company which could hinder the installation of equipment in adjacent construction sites.Relating to this, it is considered that each Safety Coordinator, when drafting the Safety and Coordination Planning, should include also the claims contained in the General Construction Site Planof the related construction site.
In particular, the plan include a series of graphical documentswhich relate to: the partition in transit areas, with the aim to better organize the spaces management; the identification of vehicle accesses to the old townand the mainviable ways of which the smallest dimensions of roadway are given; the identification of the already working construction sites; the indication of spaces to be allocated to each construction site (crane, storage areas, scaffolds); the arrangement of an emergency plan; a more detailed evaluation referring to the dimensions of the streets and the resulting biggest dimension of the scaffolding that could be installed, in order to preserve the viability.
In all the documents, the area of the Municipality is analyzed as a single construction site, without considering special provisionsfor each built-up area; it is considered the whole old townby analyzing all the featuresin order to evaluatethe possible risk scenarios.
The general construction site plan of Villa Sant'Angelo, for its importance, is considered to be a "pilot project",because it has got all the features to be presented to the other municipal administrations in the area hit by the earthquake, as a practice to be preferredin the field of reconstruction. Nevertheless, the project has never been taken into consideration by the Municipality of L'Aquila and it is not clear the reason of it. In respect of this, it is necessary to make some considerations: the widthof the surface area of the Municipality of L'Aquila is almosthundred times bigger in comparison with that of Villa Sant'Angelo, that is a small hamlet with only 427 inhabitants; moreover, the old town of L'Aquila is characterizedby a considerable culturalheritagethatmakes itone of the main medieval centerof central Italy. On the base of these evaluations, the municipality's choicenot to consider a planning toollike that of Villa Sant'Angelo could seem nearly forced, however it is still unjustified. The result of those

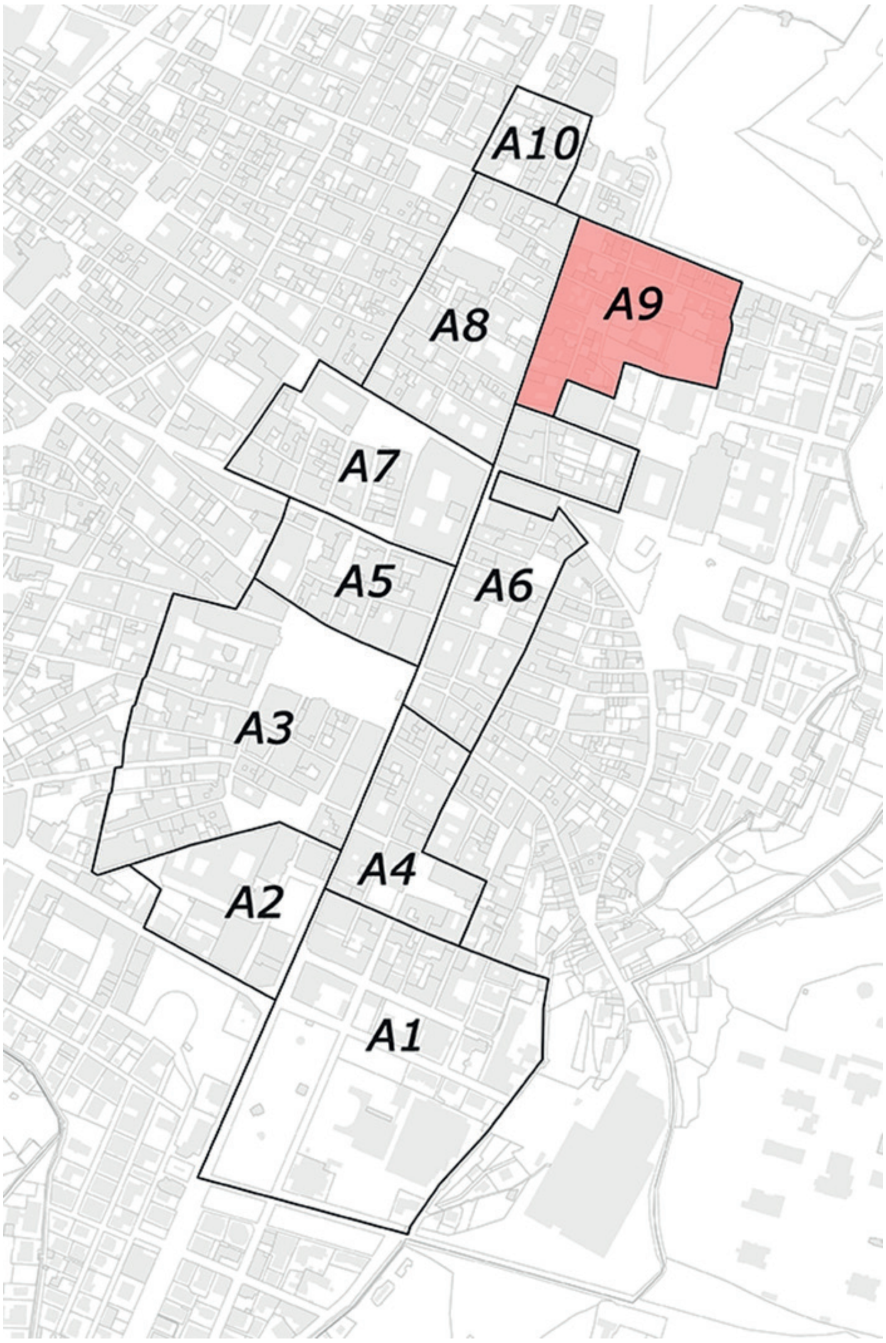


Figure 2: Compartment 9 of the central axis

choicesis in fact clearin the troubled situationsthat can be found in the old town of L'Aquila. A striking example of this is the well-known problemrelated tothe multitudeof working cranesin the city old townand the connected problemsdue to interferences. **(Fig. 01)**

GENERAL CONSTRUCTION SITE PLAN IMPLEMENTATION: THE CASE STUDY OF L'AQUILA

Without the drafting of a general construction site plan, the reconstruction process risks to be abandoned to the private initiative. The result, as it actually happened in the old town of L'Aquila, is that the choices of the building company that receives first the grant for starting the works, could hinder the organization of the adjacent construction sites, making them start later with the work implementation.As in the plan issued by the Municipality of Villa Sant'Angelo, also for the old town of L'Aquila it is proposed the elaboration of a method aimed to define the technical guidelines to create a safer and more efficient construction site. More specifically,an example of implementation is suggestfor a section of the central axis of the city old town. The central axis is an area of the old town of L'Aquila thatstretches alongthe main guideline (Corso Vittorio Emanuele). This is the city fulcrum, but at the same time it is also the most problematic area, because it has got all the main, unique features of Italian old towns: narrow alleys, structural units belonging to different historical periods, non-uniform construction techniquesetc. In addition to those singular features, there are also other features which distinguish an old town hit by an earthquake: the implementation of cumber some safety works, unstable buildings, ruins on the ground, restricted areas, but in particular the co-existence of many activities and subjects of a different kind (Firefighters, Army, citizens, technicians, designers, workers etc.). In order to manage at best the reconstruction of the central axis, the Municipality foreseen the partition of this area into compartments, each of whichhas got different dimensions and features.The compartments that make the central axis are 10, but itis take into account only the compartment number 9. **(Fig.02)**

The general construction site plan, besides giving informationon waysto start the work, includes the provision of criteria for intervention priority. More specifically, two priority levels are defined, one for compartments,the other for building aggregates. For what concerns the first level, it is take into account: the existence of main housesand commercial activities; the strategic positioning referred to the presence of wide areas that can be usedfor construction sites and to the presence of an adequate viability; the existence of collapses ordemolished/ that have to be demolished buildings. For what concerns the second priority level,we have to evaluate: the habitability results of each building aggregate; the location of the intervention, while taking into account the existence of widening and easily viable streets nearby the building aggregate; the intended use, by giving priority to houses and to commercial activities.

More in detail,the suggested general construction site plandevelops in two phases: exploratory phase and implementing phase.

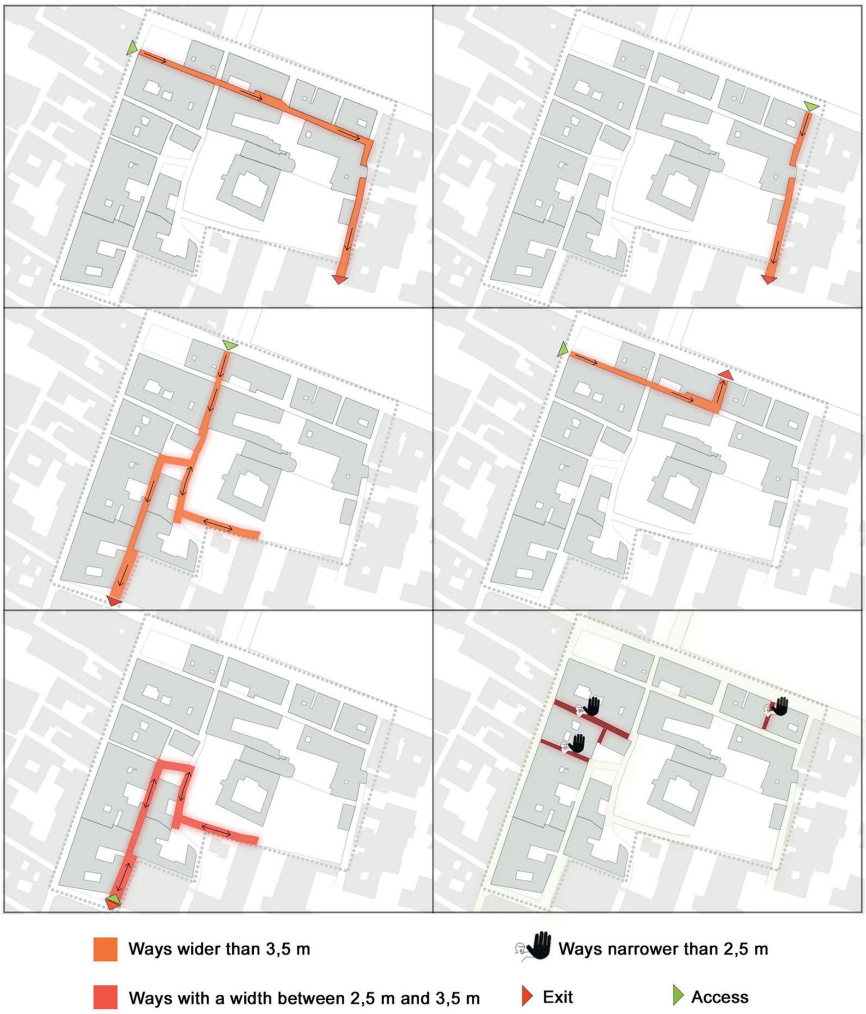


Figure 3: Way typologies identified on the base of their dimension

The exploratory phase of the plan

The first step of the exploratory phaseincludes thecompartment framinginto the old town and the mapping of thehabitability results of each building aggregatethat constitutes it. After this, it must be identified the possible accesses to the compartment, directions of travel and the viable ways, of which must be reported the smallest dimension. In this way it is possible to establishwhich of them must be limited and to whatkind of means can circulate. In the compartment 9 it is possible to identify three typologies of way: ways narrower than 2,5 m, which could not circulate; ways with a width between 2,5 m and 3,5 m; finally,ways wider than 3,5 m. **(Fig. 03)**

Once having analyzed the viability it is possible to evaluate the existence of areasthat, considering dimensions and accessibility,can be used as operative logistic centersof construction sites within a compartment.In the same analysis are also taken into account all those smaller areas as, for example, courtyards, widening, small squares that can be destined to the installation of equipment and infrastructures of construction sites.

The implementing phase of the plan

Knowing the frame ofcompartment features, in this stage it is possible to set the requirement concerning the building aggregates construction sites. Firstly, it must be defined the hypotheticlocation of cranes for each building aggregate, considering those as simultaneously active. Then,we proceed with the interferences evaluation: in case those do not allow to safely carry out the activities, we have to evaluate the priority of intervention among the examined building aggregates, by establishing which construction site should cease. In this way it is possible to define two stages of construction sitein which the requirements about the safety in the use of lifting machineries are met. **(Fig. 04) (Fig. 05)**

With reference only to the phase 1, the scaffolds typologies that guarantee an easy and safe viability for the construction site and first-aid vehicles are defined. Because of the existence of small ways, it is preferred the use of scaffold with narrow start. The construction companies should respect the maximum dimensions of encumbrance that have been reported in the plan. **(Fig. 06)**

Figure 4: Cranes plan, phase 1
Figure 5: Cranes plan, phase 2

Once having defined the scaffold typologies, it must be calculated the dimension of ways excluding their encumbrance, in order to definethe typology and dimension of means that can circulate.

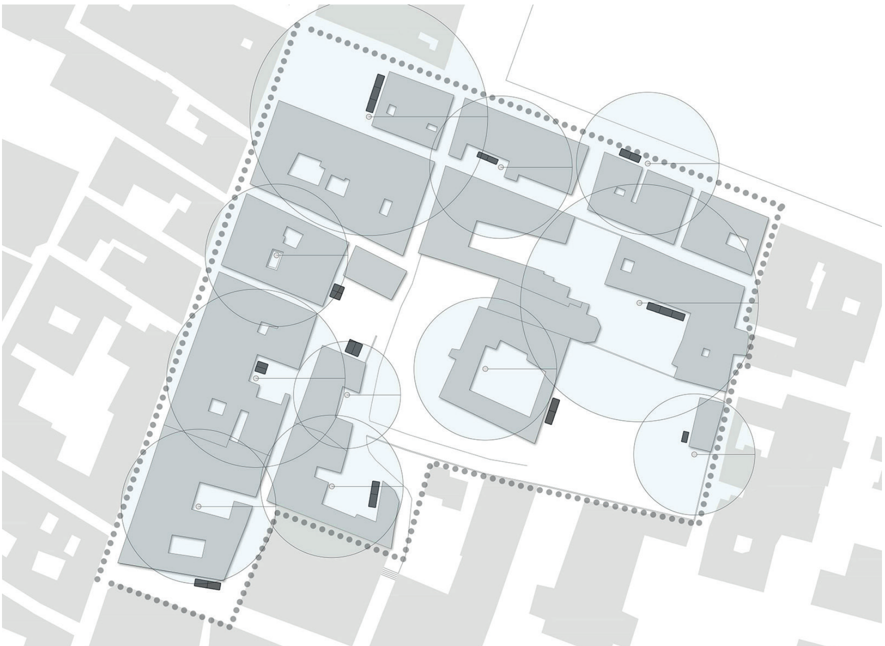
On the base of access viability to each construction site and of the areas destined to the setting up of those, it is established – approximately – the typology of temporary containers for rubble.

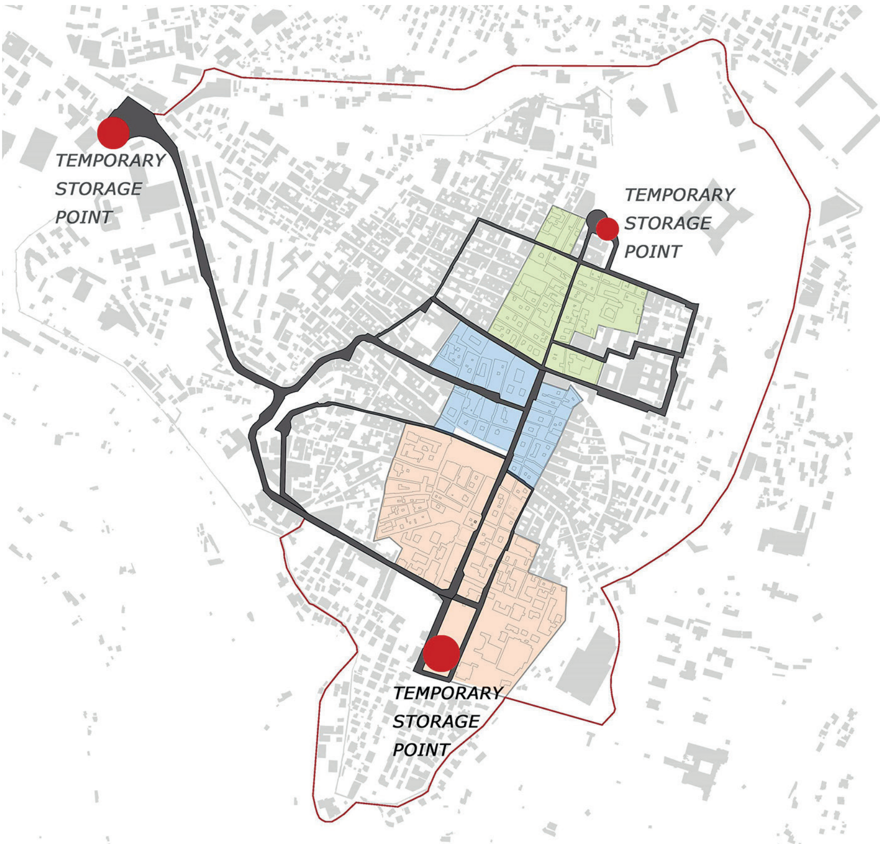
First of all, it is necessary to quantify the rubble generated for each building aggregate. Unfortunately it is not possible, for this kind of analysis, to access whole and truthful datato quantify the rubble production. To obtain an approximate esteem, then,at first it is calculated the empty volume times full volume of buildings. After this, it must determined the incidence of rubble on m³ of a building, referring to the paperabout the esteem quantifying rubble drafted in 2010 by the Institute for Construction Technologies in cooperation with theNational Fire Department. In this document it is reported the incidence of the damage-extentlevel on the total rubble volumeon the ground. Because it has not been possible to definethe level of damageof each building in the data sheets AeDES, it has been considered the worst circumstance. Then, it has been associated to each building aggregate evaluated as condemned the higher level of damage.This, by following the directives of the above-mentioned paper, affects the volume of rubble with a percentage of 1. You obtain, in this way, for each building,the approximate rubble volumethat it is possible to generate. Having obtained those results, while considering the dimension of builder skipsavailable on the market, it can be evaluatedthe necessary amount of those to be foreseen in each construction site, by taking into account the meters squaresfor each building aggregate and, in particular, on the base of the dimensionof the access way to this area.It is necessaryto evaluate which means can transit, by considering theencumbranceof scaffoldsand needed maneuver spaces and, by taking this into account, also the size of the builder skipthat has to be positioned. **(Fig. 07)**

Figure 6: Typologies of considered scaffolds

Integral element of the general construction site planis the rubble transport plan. For the rubble storage,the Municipality identifiedexternal areas to the construction site of L'Aquila, which have got the appropriate features for containing a great quantityof materialand that will be the "attraction points" towards which small vehicles coming from many working construction sites in the old town will head.In light of this, it is necessary to evaluate the traffic level of the vehicles that every day will carry the rubblefrom the construction site to the storage points, often located many kilometers away from the old town. For this reason three strategic choices have been developed:

1. In order to lower as much as possiblethe ways overload, it is proposed the identification of temporary delivery points, near the old town, used by a variable number of compartments. The rubble coming from many construction sites will be drop off in those areas and later will be carried in storage areas identified by the Municipality, by bigger vehicles. After this, the central axis is divided into transit areasand for each one it is determined a temporary storage point and established the service

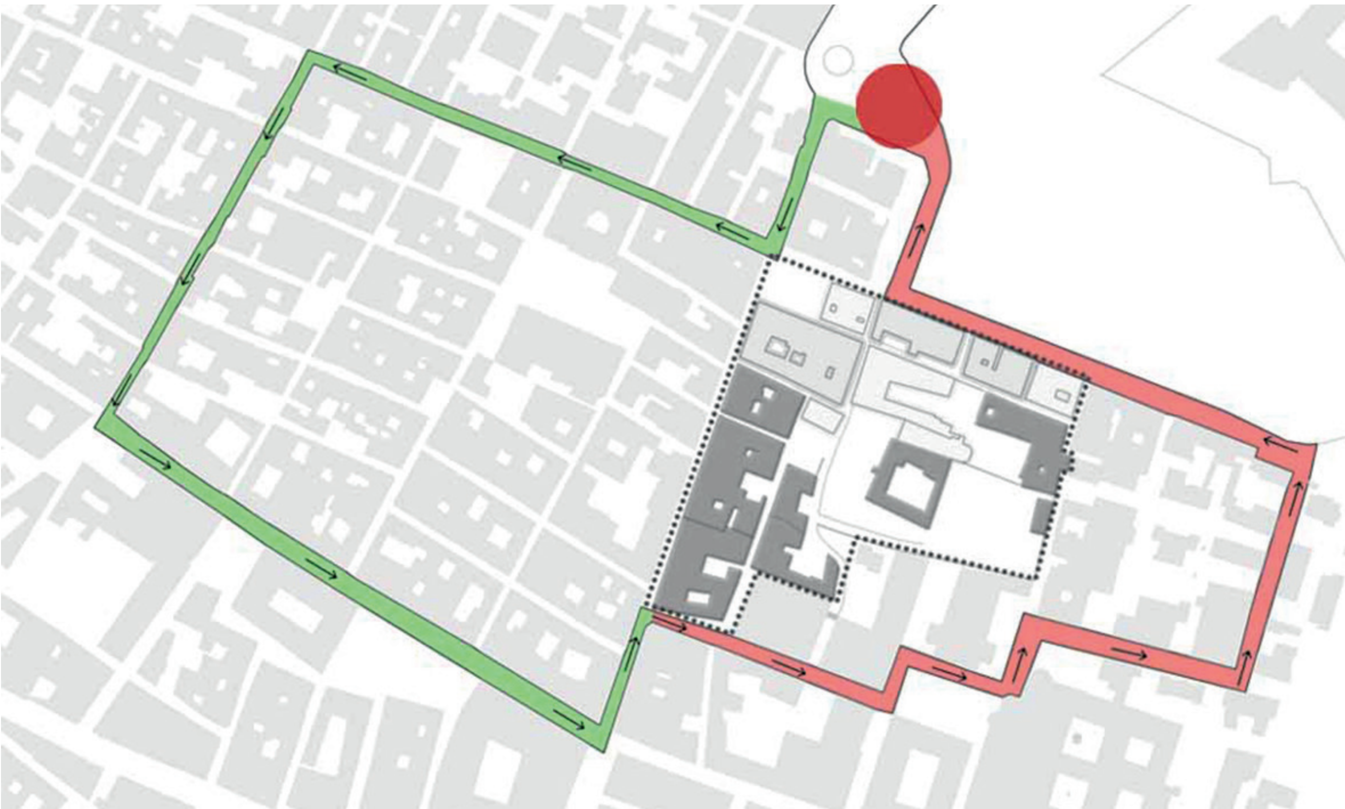




viability. In making this partition, it has been followed the statement of the present directions of motion. Moreover, the logic behind the identification of the boundariesof each area based on the willing to guarantee a fair distribution of rubble quantity for each delivery point. **(Fig. 08)**
Once having set the transit areas, it is carried out an analysis on viability of means of the compartment n° 9, included in the transit area 1. More specifically, at this stage are analyzed the accessible routes that connect the contemplated compartment with the temporary delivery point. Then, two different ways are identified, on the base of the building aggregate location. Those are the only possible ways to be transited, in order to allow the rubble disposal. **(Fig. 09) (Fig. 10)**

2. The second strategic choice refers to the transport means: it is considered, for each construction site, the use of a single mean . In this way there is the willing to reduce the environmental impact caused by the trafficof construction site means, but not only. The final aim is to lower the negative aspects related to the traffic of those kind of means in urban areas as, for example, traffic jam, the noise and atmospheric pollution and car accidents. It must be taken into account that only in the compartment 9 is contemplated, in the first phase, the simultaneity of 11 construction sites andcan be approximately foreseen the same number for all the other compartment of the central axis. It is clear, so,that the issue of rubble transportation must be facedby having the reduction of such a traffic as a priority, in order to better manage the rubble removal and to guarantee greater safety.
3. Finally, the choice connected with the production of rubble is strictly related to the one I mentioned above. By considering the transit of a single mean for each construction

Figure 7: Map of the builder skips
Figure 8: Three different transit area and temporary storage point



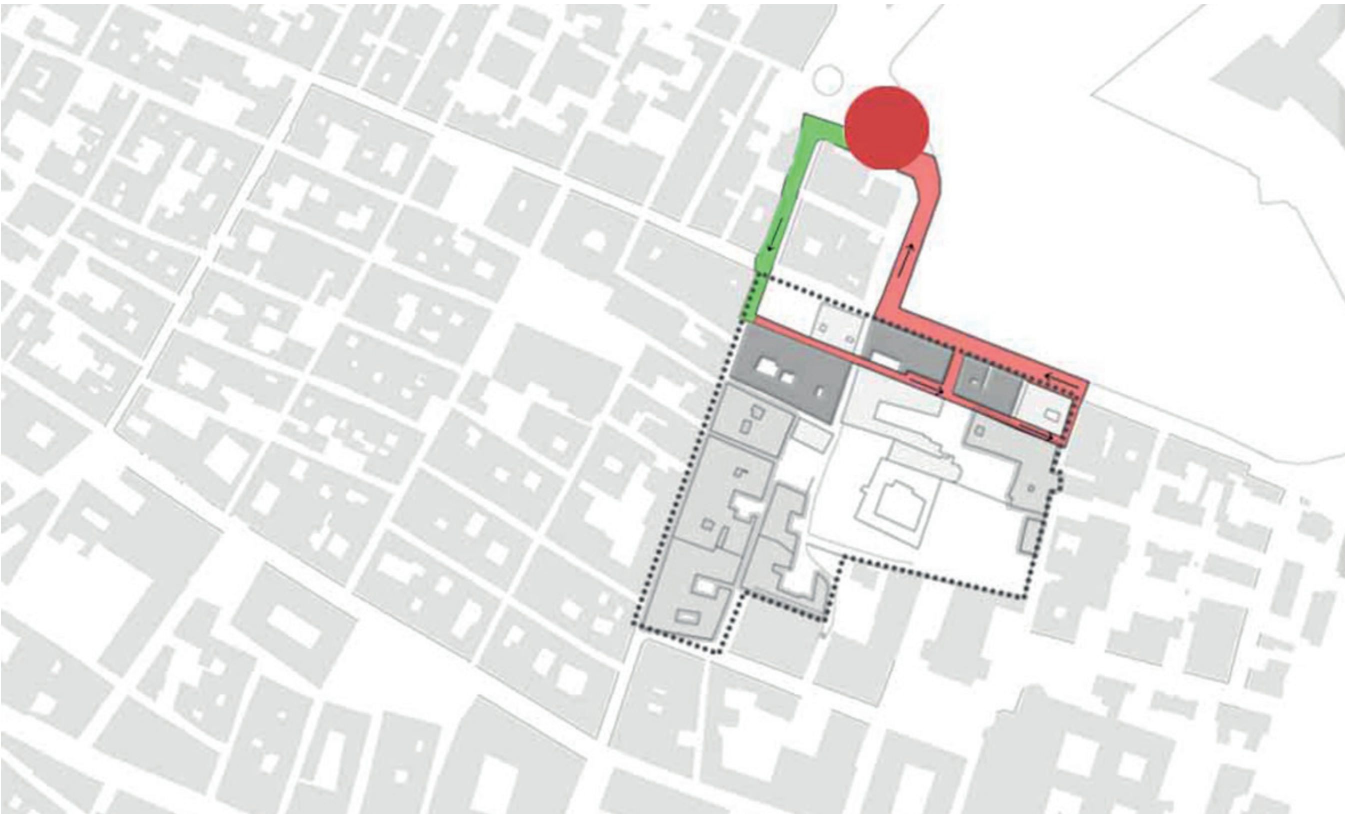


Figure 9: Route A
Figure 10: Route B

site, it is necessary to identifyan upper limit of rubble quantity that can be generated, in order to guarantee their transportation within the workday. It is set for each aggregate: the means typology that is possible to use for the material transportation; the path length from the point of rubble loadingto the point of delivery and from this last one to the starting point; the time spent for loading/delivering the material is the same spent to cover the whole path. In this way it is possible to determinethe maximum rubble quantitythat can be carried in a workday and determining, accordingly, a demolition timeline.

Those decisions let us obtain on the one hand asafer viability, both at a construction site level and at a urban level, considering also the presence of technicians, law enforcement and State military special forces. On the other hand,those choices zcause an extension of the work phases because of a slower waste disposal. This result, however, must be compared with the situation in which it is not foreseen a general construction site plan. Without it works would be faster, but with poor organization and left to the private initiative, while causing high trafficin the ways of the old town and more interferences among many adjacent construction sites.

The activities included in the plan represent a sequence that can be standardized. The following flow chartresumes the choices, the analysis and the strategies depicted in this work, showing that the method can be applied to all the old towns hit by earthquakes.
It is necessary to state that data used in this analysis are rough and often based on the event of the worst conditions. For this very reason, the plan realized for the compartment n.9 could be a model to create a real planning tool that can be applied as a valid alternative to the modus operandi of L'Aquila. (Fig. 11) (Fig. 12)

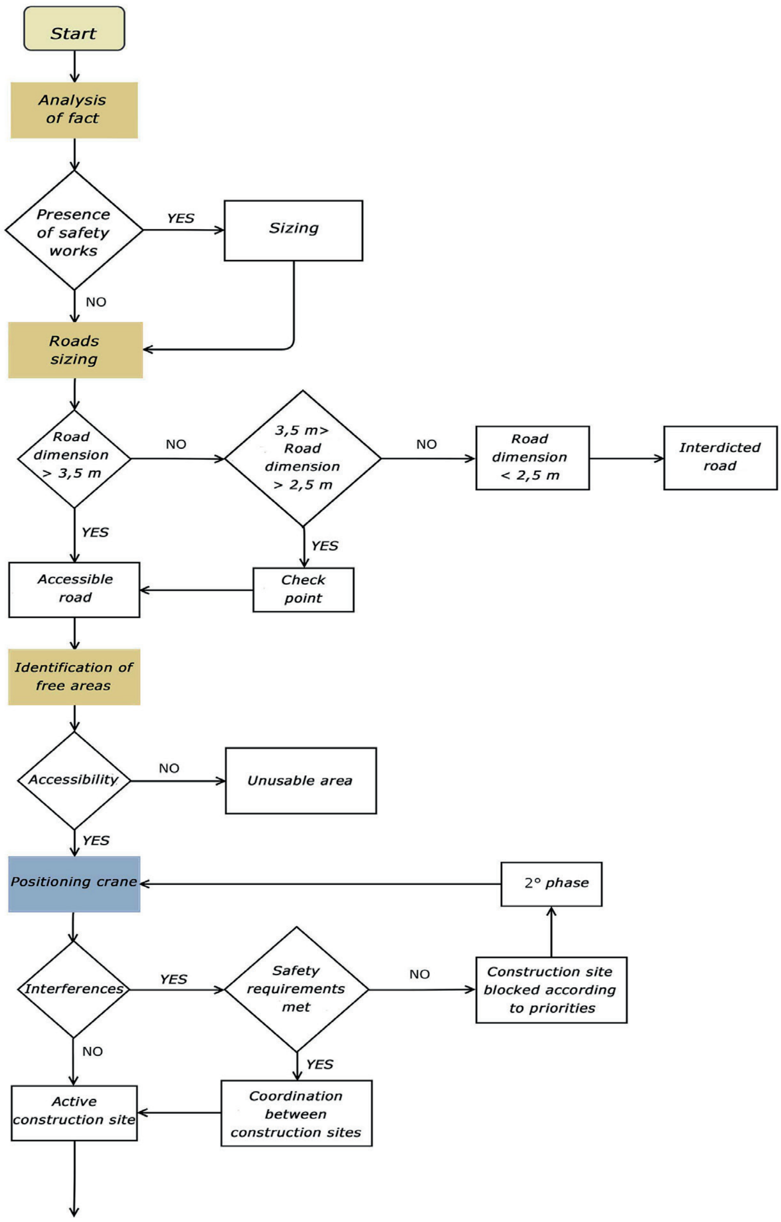


Figure 11: Flow chart

CONCLUSIONS

The requirements set for the compartment 9 can be extended and acted in all the compartments of the central axis.Through the implementation of the preliminary study included in the plan, in fact, it is possible to know the features of places, the major problems related to the construction site and to obtain a deeper knowledge of the whole area. On the base of this,i twill be possible to set the guidelines, essential for the construction site, for working safely and for the disposal of waste materials.It will be identified, in relation with priority criteria, a first phase of construction site of the whole central axis,in which the interference among adjacent construction siteswill be few and managed easily. The reconstruction process will be more effective and, in particular, supervised by the municipal

authorities, who through the general construction site planwill be able to have a global vision on all the activities carried out in the old town. With the application of the guidelines the reconstruction site will be certainly be longer, but on the other hand it could be found to respond to one of the main problem of the L'Aquila case, that is the repopulation of the old town. Until now there are many case in which the owner of a restored private house is having to live in a place surrounded by many construction sites, without any services and consequently in an uninhabitable place. For this reason the strategic choices that distinguish the analysis of this plan aim both to enhance the use of public spaces and to make an homogeneous reconstruction process, well organized and set by following objective criteria. Providing for the contemporaneity of as many activities as possible, the plan allows for the reconstruction of several compartments at the same time.
The L'Aquila experience gives the possibility to employ new methods for the management of the reconstruction. This is why the general construction site plan represents an initial contribution to improve the procedures implemented in L'Aquila. It could be interesting to extend this method for all the most recent earthquake sites and so as to make the plan a procedure to be included in the competent activities of the public administrations.

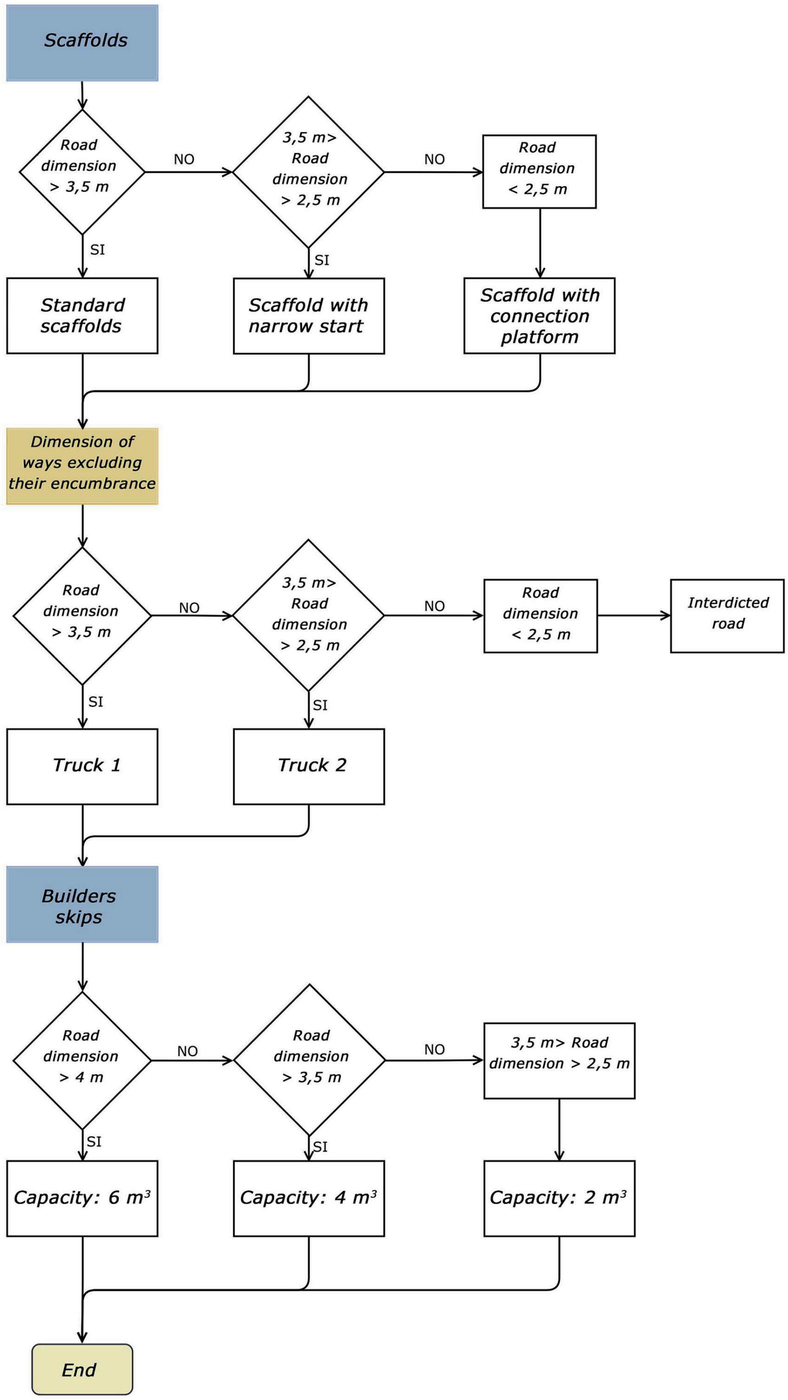


Figure 12: Flow chart

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LCA and LCC Analysis for the Programming of Sustainable Interventions on Building Heritage

KEYWORDS: Life Cycle Costing, Life Cycle Assessment, Suinstability, Roof, Life Cycle

The objective of the research is to deepen the importance of the use of the Life Cycle Assessment and Life Cycle Cost methodologies as decision support tools in the planning phase of interventions on the building heritage, in order to identify and plan sustainable choices for the renovation of the built. An initial theoretical treatment analyzes the concept of sustainable development starting from the analysis of the current environmental policies of the European Union; Life Cycle Thinking is a sustainable approach that allows you to move from the traditional design process to a global vision of the production system, which includes all the impacts that the product has in its life cycle.
It often happens that sustainability is reduced to the energy aspect only, leading to identifying the existing building heritage as a source of energy waste and consequently of pollution. From this point of view we often come to adopt extreme resolutions ranging from invasive redevelopment interventions, to abandonment or demolition and subsequent reconstruction. But in reality these choices, oversizing the load of the interventions, can determine a greater impact given the high waste of environmental and economic resources. On the contrary, the preservation of existing buildings can lead to less negative consequences, especially if addressed in a sustainable way.
The second part of the work consists in the use of LCA and LCC methodologies to evaluate and compare the environmental and economic profile of two different intervention strategies on a hypothetical 50 m² concrete slab roof, interested in extrados from an advanced state aging of the waterproofing coat and the intrados from mold and moisture spots caused by condensation
surface. The results of the analyzes provide several interesting indications of an environmental and economic character, useful for the conscious adoption of design choices oriented to the sustainability of the entire life cycle of the building element.

INTRODUCTION

Growing fears about the future of the availability of raw materials and of energy supply "push" towards rapid change: the transition from a society that sees a continuous and uncontrollable growth in consumption to a model of society oriented towards sustainable consumption, in which growth economy is harmonized with environmental and social needs. This is the new challenge of the future.

A fundamental task in the implementation of a story belongs to the construction sector, that is responsible at European level of about 42% of final energy consumption, of 50% consumption of raw materials, about 35% of greenhouse gas emissions and about 50% of waste production. Impacts attributable mainly to the comparison residential (which represents about 46% of the total building stock), and in lesser measure to the non-residential sector (31%) and civil engineering (23%). In this perspective, the fundamental data are based on maintenance strategies and constructive technologies able to optimize the use of environmental resources.

The present study is aimed at reiterating the importance of the use of the Life Cycle Assessment and Life Cycle Cost methodologies as decision support tools in the planning phase of interventions on the building heritage; in order to identify and plan sustainable choices for the recovery of the built. Specifically, it describes the application of the LCA and LCC method to evaluate and compare the economic and environmental impact of two different intervention strategies that affect a horizontal opaque closure building component. The objective is to identify the less impactful construction technology through an integral "cradle to grave" analysis.

In particular, environmental assessments were conducted with the help of the SimaPro software. The intervention on a 50 m² latero-concrete roof slab, without a thermal insulation system, was suggested, interested in the extrados from an advanced state of aging of the waterproofing layer (fig.1) and the intrados from spots of mold and moisture (fig 2).

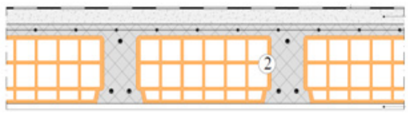
MATERIALS AND METHODS

Life Cycle Assessment

Objective and scope

To solve the problem described briefly, an external thermal coat has been provided, ie the insertion of the insulating layer in the stratigraphy of the slab, both according to the "hot roof" system and the "inverted roof" system, as well as the rebuilding of the internal plaster. An intervention on less than 25% of the gross dispersing surface was hypothesised, thus returning, according to the D.M. 26/06/2015, in the category of interventions energy requalification for which the application of the minimum requirements defined in Attachment 1 - Appendix B is mandatory. Paragraph 1.1 shows the limit values of the characteristic parameters of the building elements in the existing buildings subject to energy requalification. In order to define the climate zone, the analysis was contextualized by hypothesizing the location in the Municipality of Pomigliano D'Arco (Naples) (Climate zone C – Degrees-Day 1127). Having to guarantee a final thermal transmittance of less than or equal to 0.34 W/m²K, the two energy requalification interventions have been designed starting from the unit thermal transmittance of the existing floor, calculated through the known relation:

$$U = \frac{1}{\frac{1}{h_i} + \sum_{i=0}^{n} \frac{s_k}{\lambda_k} + \sum_{j=1}^{m} \frac{1}{C_j} + \frac{1}{h_e}}$$



It is obtained that the unit thermal transmittance of the roof slab is equal to 1,493 W/m²K. The thermo-physical parameters relating to the materials and the floor have been obtained from the UNI 10351 and 10355. At this point it was possible to choose and size the insulating layer to be inserted in the two different stratigraphy.

The project alternatives will be defined as follows:

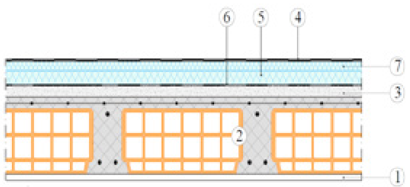
- Alternative A "Hot roof"
- Alternative B "Inverted roof"

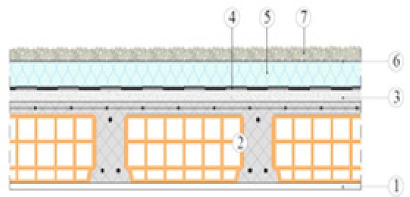
Alternative A

In the field of flat roofs, the type of hot roof is certainly the most widespread. As far as the stratigraphy is concerned, the alternative A (fig. 4) first involves placing on the cementitious support, by means of sludge, an armored elastoplastomeric waterproofing vapor barrier membrane (6), then an insulating layer (5) (7) and finally the waterproofing sheath also flattened near the veil glass that covers the outer insulation panel (4). The advantage of this solution lies in being known and applied for a long

Figure 1: Old demaged sheath
Figure 2: Surface affected by mold and moisture
Figure 3: Original section

time, reducing in this way the possibility of errors. Furthermore, the insulation, protected by the waterproofing layer, retains its characteristics and performance for longer and does not undergo the leaching effect. In this regard, the use of expanded polystyrene panels is foreseen extruded XPS coupled to each other for a total thickness of 8 cm, material chosen both for its high insulating capacity and because it is able to respond to higher requirements of resistance to compression and humidity. Its position under the mantle makes it necessary to use, for the outermost layer, a pre-coupled XPS panel with a bituminous membrane. The decision not to use a single panel is dictated by maintenance and economic issues that will be dealt with later. Moreover, given the absence of heavy protection, a mechanical fixing is provided, made with 5 expansion blocks per panel (one in the middle and the others in the corners, at a distance of 50 mm from the edges).





The thermophysical parameters relating to the materials and the floor have been obtained from the UNI10351 and 10355. We obtain Unit thermal transmittance U = 0,325 W/m²K (U_{limit} = 0,340 W/m²K).

Alternative B
In contrast to the warm roof, in the inverted roof (fig. 5) the bituminous mantle (4) is laid under the insulation (5), always made of extruded polystyrene panels of 8 cm, but this time laid dry. This stratigraphy allows to protect the waterproofing layer from thermal changes, keeping it at temperatures close to those of the carrier, and also allows the elimination of the vapor barrier, whose function is directly performed by the sealing layer. To protect the insulating panels, a synthetic felt is installed and then a heavy protection in washed round gravel, which also allows access to the roof for maintenance work.
The thermophysical parameters relating to the materials and the floor have been obtained from the UNI10351 and 10355. We obtain Unit thermal transmittance U= 0,327 W/m²K (U_{limit} = 0,340 W/m²K).
The definition of the boundaries of the analyzed systems consists of a necessary step to be able to construct the environmental balances of the LCA analyzes.
Therefore it was necessary to divide the life cycle phases of the two design alternatives into four groups:

- Production, which includes the off-production phases;
- Execution, which includes the phases of execution in work;
- Maintenance, which includes the phases of execution triggered by possible maintenance interventions;
- Decommissioning, which includes all the end-of-life phases.

Inventory analysis
The second phase of the Life Cycle Assessment forms the core of the analysis and consists in the quantitative and qualitative collection of data regarding the flows of matter and energy entering and leaving the two systems.
For this reason it was necessary to associate the materials and processes, involved in the different phases analyzed, to the data present in the databases available in SimaPro.

Phase of production
The following tables indicate for each material the correspondence with the databases used by the software, the source and the quantity required.

Alternative A				
Building material	**Simapro corresponding**	**Source**	**Quantity**	**Unit**
Vapor barrier	Bitumen sealing VA4, at plant/RES U		100	
Bituminouswaterproofing membrane	Bitumen sealing V60, at plant/RES U		400	
Polystyrene extruded XPS	Polystyrene extruded XPS, at plant/RER U	Ecoinvent system process	140	Kg
Acrylic varnish	Acrylic varnish 87,5% in H2O, at plant/RER U		25	
Cement plaster	Base plater, at plant/CH U		1500	

Alternative B				
Building material	**Simapro corresponding**	**Source**	**Quantity**	**Unit**
Bituminous waterproofing membrane	Bitumen sealing V60, at plant/RES U		400	
Polystyrene extruded XPS	Polystyrene extruded XPS, at plant/RER U	Ecoinvent system process	140	Kg
Gravel	Gravel, round, at mine/CH U		3000	
Cement plaster	Base plater, at plant/CH U		1500	

Figure 4: Alternative A
Figure 5: Alternative B
Table 1: Simapro corresponding for the building materials

Phase of execution
To reduce the environmental impacts due to transport, the materials used for the interventions come from local factories. A choice that recalls paragraph 2.6.5 "Distance of supply of construction products" of the D.M. January 11, 2017, where it is required, for the award of the rewarding score, that at least 60% by weight of the materials used for the intervention are extracted, collected or recovered, as well as processed, within 150 km of the shipyard where they are put in place.
In the following tables, the distance of the production sites from the site and the type of transport is defined for each material (Table 2).

Furthermore, the energy consumption resulting from the use of the plaster demolition equipment and the mechanical fixing of the XPS panels for the hot roof have been estimated (screwdriver drill 3,42 kWh, demolition hammer 13,80 kWh).
As well as the consumption of water for the reconstruction of the plaster equal to 320 liters, and the consumption of propane gas for the laying of a single layer of bituminous membrane (propane gas torch 9 Kg).

Phase of maintenance
For the impact analysis, a useful life of 60 years was considered, for which it was possible to define the temporal cadences of the maintenance interventions envisaged for each intervention strategy. The investigations carried out to date, on existing roofs, have shown that the concept of durability of an impermeable mantle should not be separated from the system in which it is inserted, from interactions with other layers and from the presence or absence of a heavy protection able to protect it from incident solar radiation, from temperature changes, from wind and hail and other mechanical stresses. The duration of the waterproofing layer is strictly connected to the stratigraphy in which it is inserted and to the correct design of the latter.
In 1994, architect and physicist Jon-Duri Vitac completed a 16-year research on the flat roof waterproofing systems built in Switzerland. According to the author, with regard to the problem of durability, the best results were obtained with the systems where the mantle is protected, estimating for solutions such as the inverted roof a duration of 45 years. While in flat roofs covered with traditional stratigraphy and without protection, where the mantle is made of polymer bitumen membranes, the estimated duration is 25 years with poor defects. The findings published by the British Flat-Roofing Council in 1995 include the results published by the British Flat-Roofing Council in a research conducted by Napier University of Ediburg on the durability of the flat roofs. The report estimates a 20-year duration for traditional multilayer bituminous systems if reinforced with non-woven polyester fabric and a 25-year shelf life for membranes made of polymer bitumen membrane. In both cases, according to the report, there are no protection systems.

In conclusion, the life span of a bituminous mantle is 20/25 years when it is placed inside a hot roof system without protection, of 40/45 years when instead it is an inverted roof solution.
For the two alternatives analyzed, it was envisaged the use of non-self-protected bituminous membranes, ie without the protective layer, made for example with slate or grit scales. Instead they are finished with talcum or sand, so since with the solution of the hot roof they are exposed to direct solar radiations and to the consequent high temperatures of the hot months, they must be protected with acrylic paints. The duration of the protective paint efficiency has been estimated to be around 2 years. The reconstruction of the internal plaster has been foreseen every 20 years, while in the 60 years no maintenance intervention has been foreseen to the insulating layer except for the replacement of the pre-coupled XPS panel to the bituminous membrane, present in the stratigraphy of the warm roof. Operation necessary to allow the

Alternative A				
Building material	**Type of transport**	**Distance**	**Company**	**Municipality**
Vapor barrier	Transport van <3,5t/ RES U	76,6 Km	Prebit	Battipaglia (SA)
Bituminous waterproofing membrane				
Polystyrene extruded XPS				
Acrylic varnish		22,4 Km	Malvin	Gricignano di Aversa (CE)
Cement plaster		14,7 Km	Cad	Caivano (NA)
Alternative B				
Building material	**Type of transport**	**Distance**	**Company**	**Municipality**
Bituminous waterproofing membrane	Transport van <3,5t/ RES U	76,6 Km	Prebit	Battipaglia (SA)
Polystyrene extruded XPS				
Gravel	Transport, lorry 3,5-7,5t, Euro 5/RES U	15,5 Km	Semac	Roccarainola (NA)
Cement plaster	Transport van <3,5t/ RES U	14,7 Km	Cad	Caivano (NA)

Table 2: Transport dates for the building materials

reconstruction of the bituminous mantle. It is therefore evident the economic and environmental savings obtained with the choice of using overlapping extruded polystyrene panels in the warm roof.
In summary, the following interventions were planned during the maintenance phase of Alternative A - "Hot roof":

- the reconstruction of the bituminous mantle every 20 years;
- the reconstruction of the plaster every 20 years;
- painting of the bituminous surface every 2 years.

While for the Alternative B "inverted roof":

- the reconstruction of the bituminous mantle every 40 years;
- the reconstruction of the plaster every 20 years.

The materials demolished as a result of maintenance work were considered sent to recycling or landfill, according to the following percentages:

- inert (plaster): 100% recycle;
- bituminous sheath: 100% landfill;
- XPS panel (pre-coupled to the bituminous sheath): 100% landfill.

Decommissioning phase
For the decommissioning phase a manual and mechanical demolition was considered, with the consequent separation of the materials and their load on the trucks.
The materials were sent to recycling or landfill, according to the following percentages:

- aggregates (plaster, gravel): 100% recycle;
- bituminous sheath: 100% landfill;
- vapor barrier: 100% landfill;
- XPS panel (alternative B): 100% recycling;
- XPS panel (alternative A): 52% recycling, 42% landfill.

In this first part, the consumption of resources and energy related to the entire life cycle of both solutions examined (input) were identified and quantified, arriving then to structure a real environmental balance with the help of the data provided by the SimaPro software database, such as emissions into air, water and soil (output).

Evaluation of Impacts
In this phase the extent of the environmental impacts caused by the two intervention alternatives studied was assessed. This evaluation starts from the numerical data calculated in the inventory phase and allows, through the use of aggregated indicators, for international use, to quantify the impacts and to identify the environmental criticalities. We then move from the numerical data to the judgment of danger.
With the Eco-indicator 99 evaluation method present in the SimaPro software, it was possible to quantitatively associate all consumption of resources and environmental releases to certain impact categories (formation of photochemical smog, stratospheric ozone depletion, etc.) attributable to them aimed at three major areas of general protection: Human Health, Ecosystem Quality and Resources. The results obtained from the weighing of these three categories of damage were added together (from Ecoindicator99) in a single score, called eco-indicator (Point or Millipoint), which allowed to quantify the environmental impact associated with the systems studied.

Categories of environmental impact
For each phase of the life cycle of the two design alternatives, the amount of environmental damage was therefore estimated for each impact category that belongs to the materials used.

Alternative A
In the production and execution phase, the insulating panel determined the highest impact values, in particular with regard to the ozone layer reduction.
During the maintenance phase, the greatest damage was generated by the renovation of the waterproof covering and followed by the painting intervention with the protective acrylic paint.
In the decommissioning phase the impact categories have been significantly compromised by the disposal of non-recyclable materials.

Alternative B
In the phase of production and execution of the inverted roof, the greatest damage was determined by the insulating panel in extruded polystyrene foam and by the waterproofing membrane. Specifically, the insulation was responsible in particular for damage related to the ozone layer reduction and climate change, while the membrane of carcinogenic damage to humans and the use of soil and minerals.
As for the warm roof, during the maintenance phase the greatest damage is due to the rebuilding of the waterproof covering.
In the decommissioning phase all

Building material	Type of transport	Distance	Company	Municipality
Bituminous waterproofing membrane	Trasport, lorry 3,5-7,5t, Euro 5/RER U	24,0 Km	B.Recycling	Giugliano (NA)
Polystyrene extruded XPS panel pre-coupled to bituminous membrane		12,0 Km	Eurometal	Acerra (NA)
Polystyrene extruded XPS	Trasport van <3,5t/ RES U			
Cement plaster	Trasport, lorry 3,5-7,5t, Euro 5/RER U	2,8 Km	Impianti & strutture	Pomigliano d'Arco (NA)
Gravel				
Vapor barrier		24,0 Km	B.Recycling	Giugliano (NA)

Table 3: Transport dates for the building materials

the impact categories have been compromised by the waterproofing membrane, since it is the only non-recyclable component of the inverted roof stratigraphy.

Categories of environmental damage
Subsequently, the environmental impacts that compete with the two design alternatives have been traced back to the three categories of damage:

- Human Health, measured in DALY;
- Ecosystem Quality, measured in PDF * m2y;
- Resources, measured in MJsurplus.
- The results are shown as a single score (Point - Pt).

Alternative A
In the production and execution phases, the exploitation of resources represented the most significant category of damage, mainly caused by the XPS insulation panel, the waterproofing membrane and the vapor barrier.
The rebuilding and painting of the waterproofing mantle were the maintenance interventions responsible for the greater consumption of resources and the greater damage to human health and to the quality of the ecosystem. Among the causes: the need to also have to replace the pre-bitumed insulating XPS panel, the impossibility of recycling and the high frequency in having to use acrylic paint.
During the decommissioning phase, the most significant damage categories were the quality of the ecosystem and human health. Impacts determined by the fact that most of the materials used in the stratigraphy of the warm roof ends up in landfills.

Alternative B
The waterproofing membrane and the XPS insulating panel were responsible for the greatest damage in the production and execution phases. In particular, Resources was the most compromised category of damage. As for the alternative A, the rebuilding of the waterproof covering represented the maintenance intervention with the greatest environmental impact.
In the phase of decommissioning the impossibility of recycling the waterproofing membrane has determined damage to the quality of the ecosystem and to human health. On the other hand, the impacts of the remaining materials were negligible.

INTERPRETATION

Phase of production
In this last phase of the LCA analysis, a comparative assessment was made between the two design alternatives according to the environmental impacts quantified in the previous phases. In the production phase, the alternative A presented the largest environmental load in all three categories of damage, with a total impact of 123 points. The most significant gap occurred with regard to the exploitation of resources: 79.8 Pt from Alternative B against 94.5 Pt from Alternative A.
The category of impact that indicated the greatest difference between the two design solutions and at the same time the major environmental criticality of the alternative A, regarding the exploitation of resources, was that concerning the use of minerals.

CATEGORY OF DAMAGE	UNIT	ALTERNATIVE A	ALTERNATIVE B
Human health		22,5	19,9
Ecosystem quality		6,45	5,34
Resources		94,5	79,8
TOTAL	Pt	**123,45**	**105,04**

Phase of execution
Also in the execution phase, the alternative A was the design solution responsible for the major damage, with a total environmental impact of 136 Pt versus 118 Pt of the alternative B.

CATEGORY OF DAMAGE	UNIT	ALTERNATIVE A	ALTERNATIVE B
Human health		25,7	23,2
Ecosystem quality		7,67	6,61
Resources		103	88,5
TOTAL	Pt	**136,37**	**118,31**

Phase of maintenance
A similar speech for the maintenance phase, where the gap between the two alternatives was more pronounced not only in the category of damage related to resources but also in that relating to human health.
In this case, the total environmental impact of the hot roof solution was 43% higher than the inverted roof solution,

CATEGORY OF DAMAGE	UNIT	ALTERNATIVE A	ALTERNATIVE B
Human health		73,373	46,802
Ecosystem quality		37,948	35,751
Resources		206,729	139,57
TOTAL	Pt	**318,05**	**222,123**

Table 4: Phase of production. Category of damage score
Table 5: Phase of execution. Category of damage score
Table 6: Phase of maintenance. Category of damage score

because alternative A needs more intensive maintenance during its life cycle. In fact, since the warm roof system guarantees a half life compared to the inverted roof, over the 60-year service life, it is necessary to carry out two restoring works on the bituminous surface, to which additionally the painting operations must be added with acrylic protective paint. two years.

Phase of decommissioning

Even in the decommissioning phase the alternative B was the most sustainable solution, with a total environmental impact value of 17.91 Pt compared to 24.03 Pt of the alternative A. This time, however, the categories of damage that they presented the main problems were those related to human health and the quality of the ecosystem. Damage caused by the impossibility of being able to recycle the bitumen-based material, which in the case of the stratigraphy of the hot roof system make up 86% while in the inverted roof system about 12%. The interpretation of the results obtained considering the whole life cycle, refer to paragraph 2.3.

Category of damage	Unit	Alternative A	Alternative B
Human health		11,1	8,23
Ecosystem quality		12,08	8,65
Resources		0,86	1,03
TOTAL	Pt	**24,04**	**17,91**

Alternative A		
		Costs
Construction	year 0	€ 5.576,26
Maintenance		
acrylic paint	any 2 years	€ 334,00
remake waterproof mantle	any 20 years	€ 2.267,90
remake plaster	any 20 years	€ 1.378,42
Decommissioning	year 60	€ 851,73
Alternative B		
		Costs
Construction	year 0	€ 6.977,25
Maintenance		
remake waterproof mantle	any 40 years	€ 2.874,11
remake plaster	any 20 years	€ 1.378,42
Decommissioning	year 60	€ 849,69

Table 7: Phase of decommissioning. Category of damage score
Table 8: Phases costs

Life Cycle Costing

As for the Life Cycle Assessment methodology, also for Life Cycle Cost Analysis the phases of the life cycle of the two alternatives have been divided into different groupings:

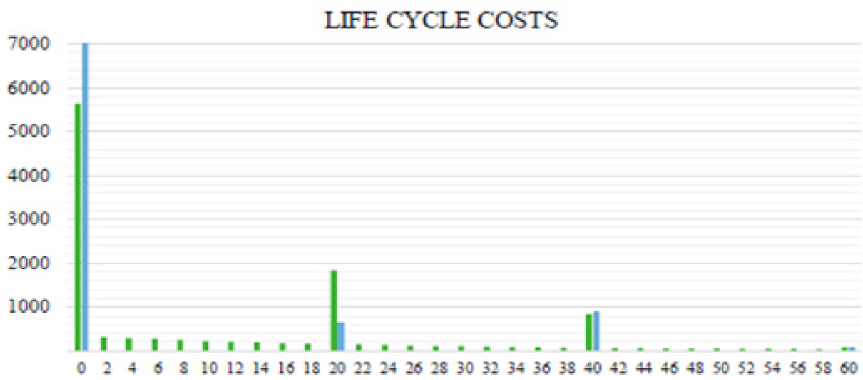
- Construction, which includes the costs due to the phases of execution in work;
- Maintenance, which includes the costs triggered by maintenance activities;
- Decommissioning, which includes the costs due to the end of life phases.

With the help of the Price List of Campania Region and external sources, if necessary, a metric estimate 40 was drawn up for the different phases of each intervention, thus obtaining the related costs (Table 8).
To these costs, it was necessary to add:

- costs related to energy consumption for the removal of plaster, to mix the fine mortar in the cement mixer and for the mechanical fixing of the XPS panels foreseen for the hot roof.
- the cost related to the consumption of 270 liters of water for the remaking of the plaster, 0.367 €.
- the cost related to the consumption of 130 liters of water for the con-struction of the subtle base screed, € 0.177;
- the cost of propane gas, used for the laying of a single layer of bitumi-nous membrane € 27.

To estimate the Life Cycle Cost of each of the two isolation systems, it is neces-sary to proceed with the discounting of the tabulated costs, so as to establi-sh the current value of a capital whose natural expiry date is a future date. It is therefore possible to identify, by applying a discount rate, a financial equivalence between the two capitals that have diffe-rent maturities over time.
To "correct" the cash flows we multiply each of them by a discounting factor (actual value of the cash flow):

$$FC_t \frac{1}{(1+r)^t}$$



The graph in Figure 6 shows the trend of discounted costs throughout the useful life of the two project solutions (in green the alternative A, in blue the alternative B).

Taking also into consideration the construction cost, the sum of the discounted costs referring to the maintenance phase and the discounted cost of the decommissioning phase, we obtained the global costs.

The following table shows the discounted costs referred to each phase of the two interventions.

	Alternative A	Alternative B
Construction	€ 5.636,75	€ 7.037,16
Maintenance	€ 6.116,02	€ 1.528,55
Decommissioning	€ 81,19	€ 80,99

RESULTS

The application of the Life Cycle Assessment and Life Cycle Cost methodologies to the present study has made it possible to evaluate and compare the environmental and economic impact of the two proposed project alternatives, and therefore to identify the most sustainable solution.

The results of the Life Cycle Assessment analysis showed that alternative B represents the least impacting choice in each phase of the life cycle analyzed, obtaining in particular a reduction of environmental damage related to the use of resources and human health of around 25% compared to the alternative A (Figure 7).

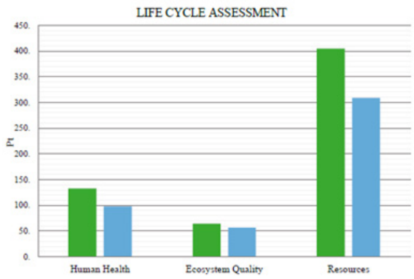
The greater environmental criticality of the alternative A, in the different categories of damage, is determined both by the need to provide for a more intensive maintenance activity and by the higher percentage of non-recyclable materials.

In this regard, considering only the waste produced by the stratigraphy of the two roofs, it is clear that the inverted roof system represents the closest solution to the European purposes regarding the recycling of construction and demolition waste (Figure 8).

The greater sustainability of the B alternative was also confirmed from the economic point of view thanks to the Life Cycle Cost analysis.

In fact, despite the higher initial cost, this alternative constitutes the most economically advantageous solution with a discounted global cost of 8646.70 euros compared to the 11833.96 euros of the alternative A.

The increase in the expenses foreseen for the hot roof was due to the maintenance phase, obtaining a difference in the maintenance costs, between the two design solutions, of 75% (Figure 9).



Furthermore, with reference to the average prices identified for the CER41 codes (European Waste Code), the costs of treatment (disposal and recycling) of waste were estimated for both design solutions, obtaining:

- ALTERNATIVE A - Total cost = € 318
- ALTERNATIVE B - Total cost = € 287

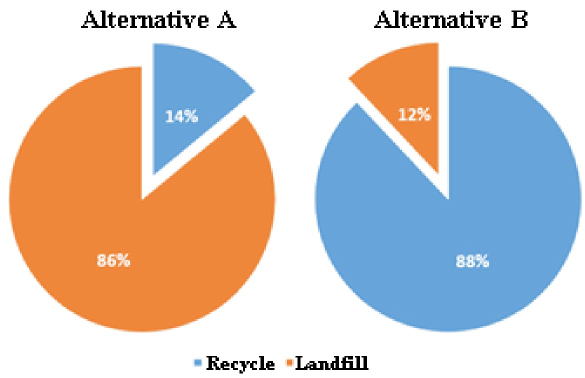
DISCUSSIONS AND CONCLUSIONS

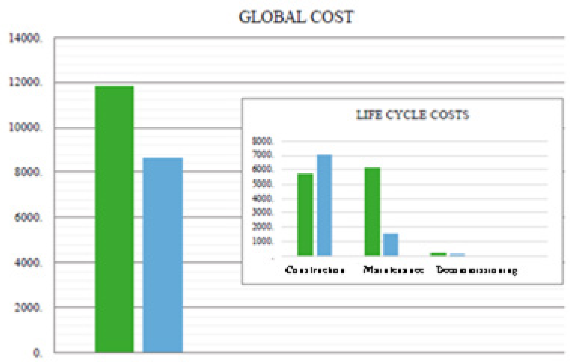
Very often the comparison in terms of economic convenience between different design solutions is carried out erroneously on the basis of the cost of realization alone.

On the other hand, forgetting that in the

Category of damage	Unit	Alternative A	Alternative B
Human health		132,7	98,08
Ecosystem quality		64,15	56,53
Resources	Pt	409,9	308,96

Figure 6: Life Cycle Costs
Table 9: Phases costs
Figure 7: Life Cycle Assessment (in green the alternative A, in blue the alternative B)
Table 10: Category of damage score





life of a building component is the rate of maintenance costs generally having a higher weight.
So the identification of the most economically advantageous solution can not ignore the use of a Life Cycle approach that allows you to have an overall economic vision, "from the cradle to the grave".
This need is clarified by the results of the LCC analysis carried out, since they show how wrong the usual belief of the constructors of considering the layer of protection in gravel an unnecessary economic burden. The latter, in fact, guaranteeing a long duration of the waterproof layer of the alternative B, allows to limit the maintenance costs to the point of reversing the result of economic convenience identified initially in the construction phase.
Added to this is the need to make the designer responsible also from an environmental point of view, so that he / she is aware that a certain design choice involves implications in terms of the impact on the environment associated with its phase of realization, use and disposal. the final. For this reason, the parameter "environmental impact" determined with the LCA analysis was included in the comparative evaluation conducted, with which it was possible to confirm once again the sustainability of the alternative B. In fact, thanks to its dry stratification, which guarantees greater reusability of the components, and the duration of its bituminous mantle, it is possible to meet the expectations of reduction of the environmental impact of the life cycle of the building intervention.
Moreover, the decision to intervene on the building envelope with a thermal coat and therefore with an energy redevelopment intervention, involves a further reduction of the impact on the environment, since decreasing the energy requirement necessary for heating decreases the amount of CO_2 that is emitted into the atmosphere.
In conclusion, it can be said that "planning maintenance" with the help of decision support tools, such as the LCC and LCA methodologies, is equivalent to "planning sustainability". The maintenance therefore exceeds the definition of "maintenance of the efficiency of the services offered" to extend to a much broader science based on the reduction of resource consumption and the accountability of behaviors.

Figure 8: Recycle and Landfill percentage
Figure 9: Global costs

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10

LCA Analysis Through a Visual Programming Tool: Workflow on a BIM Model Case Study

KEYWORDS: LCA, BIM, Visual Programming, Environmental Impact, Building Materials

BIM tools also allow to conduct various impact analysis and, with regard to the growing concern about environmental issues, they embody a valuable mean to analyse buildings process consequences thus guiding designers towards better and more aware choices.
The capacity of BIM applications to evaluate environmental issues would be enhanced if integrated with Life- Cycle Assessment (LCA) tools considered among the most suitable methods for evaluating such impacts.
However, a typical barrier in performing LCA during the early design stages, i.e. the moment that influence the most the project outputs, is the lack of project information. Usually, this implies LCA to be performed after the design phase, when all the significant decisions are already taken.
The implementation of LCA within the early stages of the design process, possibly through an automated method, can enhance the control of environmental variables hence, the integration of BIM and LCA, appears to be a suitable opportunity.
The parametric approach allows BIM-based software to collect data and connect them with model elements. In order to avoid manual compilation of complex records, Visual Programming tools can cooperate with the authoring BIM software and interrelate the model with external sources such as materials environmental impact databases. Moreover, they can be configured to perform complex LCA calculation and automatically update the outcomes when something in the model changes.
The goal of this paper is to propose a sample workflow applied to a case study, in order to provide AEC stakeholders with a simplified BIM-based method for easily detecting the potential consequence of undertaking certain design choices at initial project stages or, at least, at those phases when definitive materials and products selection occurs.

INTRODUCTION

Constructions today represent one of the minor sustainable sectors: buildings are considered responsible for the consumption of almost 50% of energy, 50% of fresh water, the depletion of around 80% of agricultural soil and 60% of materials for buildings and infrastructures (by bulk) (Edwards, 2014). Manufacturing building materials, indeed, accounts for 10% of all global energy end-use (United Nations Environment Programme, 2011).

Furthermore, buildings contribution to global pollution is estimated to reach nearly 50% in GHG emission, 40% in drinking water pollution and 50% in landfill waste and ozone depletion (Edwards, 2014).

Aiming at minimizing the impact related to building sector, several Sustainable Development strategies have been undertaken in the last decades (Ortiz et al., 2009). Policies, regulations together with tools and methods were developed to implement sustainability in the built environment (Kang, 2015).

For a long period, main attention has been given to the improvement of buildings operation, thus to energy performance, in particular with respect to heating and cooling aspects (Röck et al., 2018).

In order to ascertain the actual level of buildings sustainability and to achieve better sustainable performance, several approaches and technologies have been adopted (Chong et al., 2009) with the goal to perform assessments and comparisons.

Such tools should evaluate buildings attributes from different perspective, relying on various criteria and, from the assessment outcomes, provide effective information to be implemented in the design process allowing the comparison between different alternatives. Among the already existing tools and methodologies two in particular are able to enhance these kinds of evaluation: Building Information Modelling (BIM) and Life-Cycle Assessment (LCA).

The combined use of these two approaches, however, is still scarce: despite specific tools have reached a good level of maturity, several practice experiences of assessing the environmental impacts related to construction materials and products as part of the design process, highlight that further developments are needed to empower an optimized integration (Najjar et al., 2017).

The workflow proposed in this paper was developed (with the support of Open Project s.r.l., an engineering and architecture firm located in Bologna), as part of a PhD research in architecture technology at the University of Bologna, with the aim of promoting the environmental assessment of buildings within the common design practice, trying to overcome some critical issues that still hinder a widespread LCA application.

Although LCA is a current issue, considering both the recent European regulations on construction materials (CPR 305/2011, Directives 2014/23/EU, 2014/24/EU and 2014/25/EU) (Pachego-Torgal, 2014), and the requirements of many green building rating systems such as LEED, BREEAM and DGNB, still many practitioners do not consider environmental analysis during the design process.

The reasons usually concern the high level of expertise required, and the significant cost of some applications that, despite the capability of interoperating with BIM applications in a simplified way, do not motivate the investment.

The proposed workflow, although in a pretty simplified way, aims at providing a basis for a streamlined and convenient implementation of the LCA analysis starting from the early design stages as a guide for making more aware design choices.

LCA FOR BUILDINGS

The Life Cycle Assessment (LCA) method is considered a valuable means to evaluate the environmental impact related to buildings from extraction of raw materials, to production, assembling, refurbishment and to possible end of life scenarios. The literature recognizes it as a strategy to reduce environmental impacts and energy consumption related to the AEC industry (Ortiz et al., 2009).
LCA is usually employed in order to report several impacts throughout a selection of environmental issues involving air, water and soil quality, thus including toxicity to human
life and to ecosystem, climate alterations and the depletion of resource (renewable and non-renewable),
water and energy (Anderson and Thornback, 2012).
Standardized with the ISO 14040 and ISO 14044, LCA framework is composed by four phases: goal and scope, life cycle inventory (LCI), life cycle impact assessment (LCIA) and interpretation.
Especially for the building sector, LCA is considered a data intensive methodology, requiring a great amount of information, in particular those associated with embodied impacts of buildings materials. In the early design stages, the use of LCA is limited by uncertainties regarding the definitive list of components and the actual service life of elements (Röck et al., 2018).
For this reason, Life-Cycle Assessment are usually performed at the end of the process, sometime just for certification purposes, once the building is close to completion (when extra changes would result in significant additional costs) and all the required information are accessible. In this way, LCA cannot provide relevant feedbacks able to guide the design process and the improvement of the sustainable aspects (Basbagill et al, 2013).
Despite being more challenging, the implementation of sustainable design has to occur in the early phases when the most influencing decisions for the environmental aspects of the project are taken, having the caution of considering, at the same time, the entire buildings life cycle (Antón and Diaz, 2014).
Anyway, LCA analysis can be performed following different levels of detail and complexity. The EeB Guide Handbook (2012), for instance, identifies three type of study: screening, simplified and complete. A screening LCA may be considered for an initial overview of the environmental impacts of a building or a product, a simplified one can be performed for a quick assessment, while the complete LCA fully reflects the ISO 14040/14044 approach. The Goal and Scope definition becomes much more inclusive as the level of the study approaches the complete method.

BUILDING INFORMATION MODELLING (BIM)

The AEC sector has witnessed, over the last decades, crucial changes in the design and management approaches as a result of the development of computer-aided design (CAD) software and, lately, after the introduction of building information modelling (BIM) platforms. According to the US National Building Information Model Standard Project Committee, BIM is defined as "a digital representation of physical and functional characteristics of a facility" and represent "a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle" (nationalbimstandard.org, retrieved December 2017). Wong and Zhou (2015) defined this technology as a set of interrelating policies, processes and technologies able to endorse a systematic approach to the management of projects crucial information in a digital format, during the whole life cycle of a building. Similarly, the European Committee for Standardization (CEN) defines it as the "use of a shared digital representation of a built object…to facilitate design, construction and operation processes to form a reliable basis for decisions" (EN ISO 29481-1:2017).
When employed to achieve sustainable purposes in buildings projects, this technology meets the definition of Green BIM: "a model-based process of generating and managing coordinated and consistent building data during its project lifecycle that enhance building energy-efficiency performance and facilitate the accomplishment of established sustainability goals" (Wong and Zhou, 2015).
As for energy aspects, for which BIM platforms can enable the integration of energy efficiency design with energy consumption assessment over the building's life cycle (Yuan and Yuan, 2011), connecting BIM model to sustainability indicators and metrics, can enhance detailed sustainability trade-off analysis in order to undertake more aware decisions in the early projects phases. At the same time, this approach can stimulate similar decisions also for operation, maintenance and end of life scenarios (Wong and Zhou, 2015).
BIM processes are capable of bringing gather the diverse sets of information used in construction into a common information environment (EN ISO 29481-2:2016) thus potentially proving the overall information flow, encouraging transparency and interoperability between the stakeholders thus enhancing communication and reducing waste and errors (MacGraw Hill Construction, 2010).
BIM tools, therefore, involves the production of a digital 3D model of the building that includes a variety of physical and functional data of materials and components. In order to define the entity and the quantity of the information, some institutions, such as the American Institute of Architecture (AIA), have developed a specification reference for enabling practitioners to clearly specify and articulate the content and the consistency of Building Information Models, called Level of Development (LOD) (bimforum.org, retrieved July 2018).
LOD, hence, "describes the minimum dimensional, spatial, quantitative,

qualitative, and other data included in a Model Element" and, taking as reference the AIA guide, it is possible to identify five levels, from LOD 100 to LOD 500, characterized by increasing accuracy in describing the model content (AIA, 2013).

BIM AND LCA INTEGRATION

Due to the complex structure of constructions, made up of a wide variety of products, composed in turn of different materials, performing an environmental assessment of a whole building becomes a complicated task.
Each product, in fact, has its own attributes and service life, resulting in heterogeneous environmental profiles. Beside the scarcity of products information in the early design stage, LCA is also affected from uncertainty about operating performance and decommissioning circumstances along with transportation issues (characterized by a relevant impact on the environment) thus growing the level of initial assessments inaccuracy (Buyle et al., 2013).
Nevertheless, Life-Cycle Assessment tools, are still considered among the most suitable methods for evaluating such impacts (Röck et al., 2018) but, in the majority of cases, the assessment is performed at the end of the process.
Anyway, as previously stated, the stages with the biggest influence on the project are the early ones, when the project development is more flexible and it is easier to analyze different alternatives for improving the performance. As a matter of fact, manual management of project information through LCA tools represents a key issue as it involves redundant and potentially error-ridden activities (Antón and Diaz, 2014).
Furthermore, the employment of the LCA method for a building cannot be performed with the same precision and accuracy as for other sectors (EeB Guide Project, 2012).
For these reasons, integration between BIM and LCA is considered a possible solution, since the LCA tools would have direct access to the BIM data.
For this purpose, BIM has been mainly employed for extracting quantities in order to compile Life Cycle Inventories (LCI) for LCA (Antón and Diaz, 2014) since BIM models can contain and provide all the necessary information sorted per building materials, components or assemblies.
The importance of running simplified LCA applications for buildings has been recognized in the literature (Kellenberger and Althaus, 2009) and the integration of BIM and LCA has been identified as a possible and valuable optimization for carrying out environmental assessments (Soust-Verdaguer et al., 2016).
In this direction, it is possible to find some example of integration, such as "Tally", an Autodesk Revit extension that enables LCA calculation of the BIM model but, currently, this software is adapted to the US context.
The BIM-LCA integration, still rises some perplexities regarding the verification of the future scenarios since it involves assumptions about materials and products end of life, indicating the inconveniency of including all the life cycle phases and conducting complete "cradle-to-cradle" BIM-based analysis (Peng, 2016).

SCOPE OF THE APPLICATION ON A CASE STUDY

The BIM-based environmental assessment techniques currently available, in the majority of cases need external tools, which can hinder a fluent interoperability, especially when a lack of data compatibility occurs, thus resulting in a time-consuming format conversion (Lee et al., 2015).

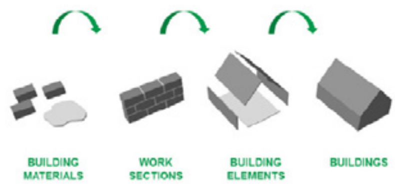
In order to overcome this issue, giving to users, at the same time, the freedom to customize the boundaries of the applications, this paper provides a simplified workflow of a BIM-based LCA analysis, that relies on a Visual Programming tool, namely Autodesk Dynamo, which can interoperate between an authoring BIM software, such as Autodesk Revit, and an external source of information (LCA dataset) enclosed in a spreadsheet (e.g. Microsoft Excel).

In this way, the analysis can be carried out directly within the BIM platform, through a customized set of parameters related to buildings materials.

The goal of this paper is to propose a sample workflow applied to a case study, in order to provide AEC stakeholders with a simplified BIM-based method for easily detecting the potential consequence of undertaking certain design choices at initial project stages or, at least, at those phases when definitive materials and products selection occurs.

The boundaries of the study are identified considering the following key aspects:

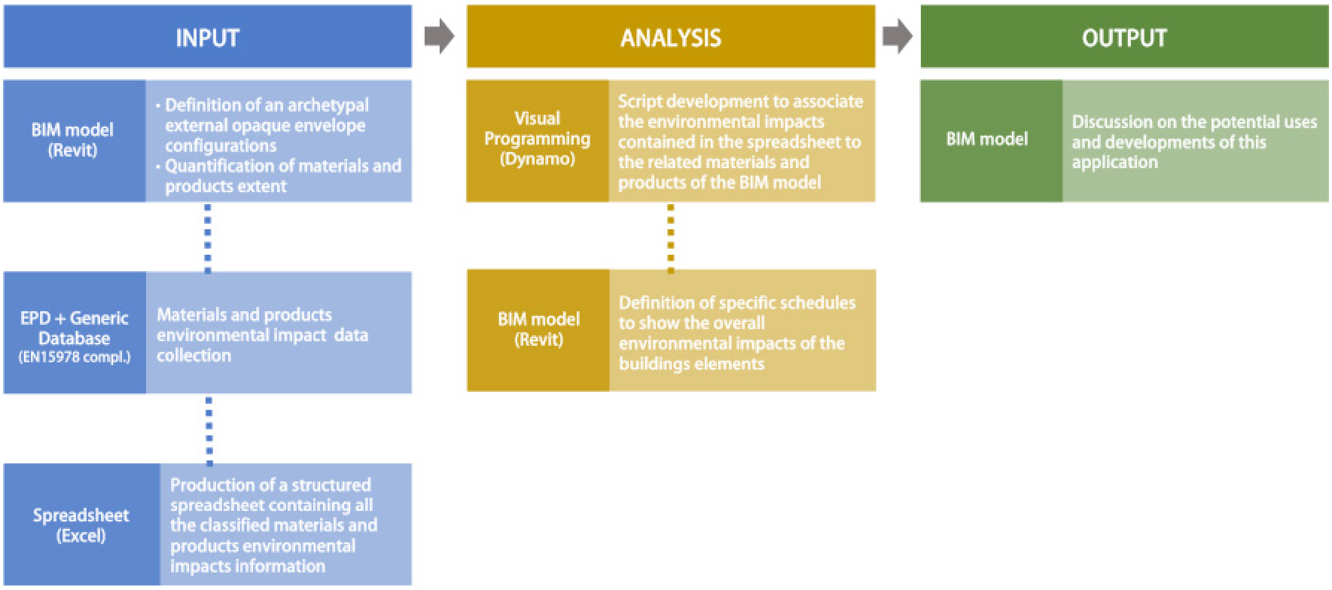
- The case study selected for the application of the workflow, a model floorplan of a multi-storey student residence, has been developed with LOD 300, by which the elements are usually detailed with specific assemblies and attributes such as quantity, size, shape, location and orientation are precisely identified. According to Soust-Verdaguer et al. (2016), this is the most suitable LOD for a correct management of the environmental implications at initial stages.
- This circumstance allows to focus particularly on the study of buildings materials and products alternatives, since preliminary characteristics have been already defined. For this reason, following the modular approach of aggregation proposed by Trigaux et al. (2014) (Fig.1), this study will consider the building materials and further aggregation as objects of the analysis, in order to produce outputs referred to the building elements. In particular, the investigation will be limited to the external opaque envelope, since it represents a key element in shaping thermal and energy performance and it covers a considerable portion of the total building surface (Azari, 2014).
- For the LCA analysis, taking as reference the classification suggested in the EeB Guide Handbook (EeB Guide Project, 2012), this study will reach an extent comparable to the "simplified" one, thus considering specific, quantitative environmental information on building elements, products, materials and components but not including all the ISO 14040/14044 and EN 15978 prescriptions. The simplified scheme adopted is shown in Table 1.
- European standards defining the environmental performance of buildings, such as EN 15978:2011, EN 15643-1:2010, EN 15643-2:2011 and EN 15804:2012, have been also taken as reference but, even if energy and water consumption during the use phase are listed as element to be included in the assessment, this study has been limited to the impacts associated with materials and products during buildings life cycle, as recognized by Malmqvist et al. (2010) as the simplest building-related application.



Building Components	External Opaque Envelope (external walls and finishes).
Life Cycle Stages	Production Phase (A1-A2-A3), Construction Process Phase (A4-A5), End of Life (C4).
Functional Unit	1m³ of Building Materials[1]
Building Service Life	60 Years[2]
LCIA Indicators	GWP, EP, AP, ODP, POCP[3]
LCI Indicators	PERE, PENRE[3]
Primary Data Source	EPD (EN 15804 compliant)
Secondary Data Source	Generic Database (EN 15804 compliant)
Reference Standards	ISO 14040/14044; EN 15978; EN 15804

[1] Functional Units provided by EPD developers not referring to a Volume unit, have been converted to $1m^3$ of buildings material, basing on Mass and Density information and Environmental Impacts have been consequently adapted.
[2] For those materials, whose Service Life differed from 60 year, related Environmental Impacts have been considered (hence modified) proportionally to the Service Life of the Building.
[3] According to EN 15978 and EN 15804 (Characterization Factor from CML-IA): GWP: Global Warming Potential [kgCO_2eq]; EP: Eutrophication Potential [kg $(PO_4)^3$-eq]; AP: Acidification Potential [kg SO_2-eq]; ODP: Ozone Depletion Potential [kg CFC 11eq]; POCP: Photochemical Ozone Creation Potential [kg Ethene eq]; PERE: Primary Energy Renewable [MJ]; PENRE: Primary Energy Non-Renewable [MJ].

Table 1: Boundaries of the LCA framework adopted in the study



WORKFLOW DEVELOPMENT AND IMPLEMENTATION

Data acquisition is the most conspicuous issue since buildings contain great quantities of different materials and the availability of reliable data is limited. In order to simplify the LCA process, it is important to select the most representative data related to few characteristic life cycle stages (Malmqvist et al. ,2010).

In order to manage the data in an optimized and replicable manner, a “common language” based on data structure and classification convention, is one of the first task of the workflow development. This convention is necessary to interrelate LCA database with the BIM model (Röck et al., 2018).

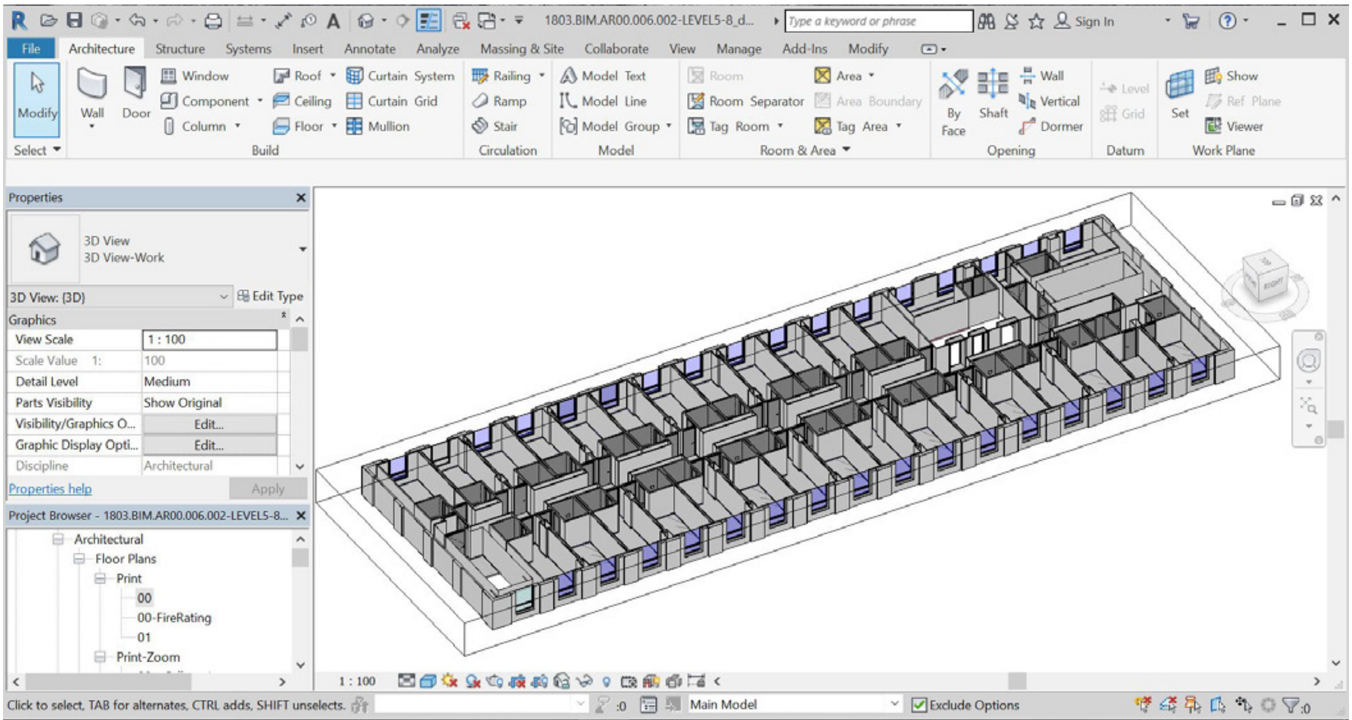
Inspired by the essential steps of LCA Design illustrated by Seo et al. (2007), who proposed an information flow divided into: “Input”, “Analysis” and “Solution”, this study relies on a similar structure (Fig.2) in which:

- the Input step includes: the definition of an archetypal external envelope configuration compliant with the national thermal performance regulation, the quantification of the envelope materials and products extent through Autodesk Revit, the collection of the LCA data from EPDs and generic database, the production of a structured spreadsheet containing all the classified materials and products environmental impacts information;
- the Analysis step involves: the evelopment of a script with the Autodesk Dynamo visual programming tool, able to associate the environmental impacts contained in the spreadsheet to the related materials and products of the BIM model, the definition of specific schedules in the BIM platform, able to show the overall environmental impacts, organized per indicator and life cycle phase and sorted per singular material or per aggregate components;
- the Output (Solution) step consists in: the discussion of the potential uses and developments of this application.

Figure 1: Modular approach of aggregation for LCA data processing (Trigaux et al., 2014)
Figure 2: Steps of BIM-based LCA Design (adapted from Seo et al., 2007

Plastboard (cartongesso) "PB" – Parametro "Life Cycle Assessment"	Product Stage							Construction Process Stage					
	GWP (A1-A2-A3)	ODP (A1-A2-A3)	EP (A1-A2-A3)	AP (A1-A2-A3)	POCP (A1-A2-A3)	PERE (A1-A2-A3)	PENRE (A1-A2-A3)	GWP (A4-A5)	ODP (A4-A5)	EP (A4-A5)	AP (A4-A5)	POCP (A4-A5)	PERE (A4-A5)
PB-Plastboard-Sheet-Standard	364,8	0,000192	0,1632	5,184	0,2208	63,36	4704	24,96	0,000011712	0,02976	0,14496	0,00528	47,136
PB-Plastboard-Sheet-Waterproof	0	0	0	0	0	0	0	0	0	0	0	0	0
PB-Plastboard-Sheet-Fireproof	0	0	0	0	0	0	0	0	0	0	0	0	0
PB-Plastboard-Sheet-Fireboard	0	0	0	0	0	0	0	0	0	0	0	0	0
PB-Plastboard-Sheet-Vidiwall	0	0	0	0	0	0	0	0	0	0	0	0	0
PB-Plastboard-Sheet-Aquapanel	0	0	0	0	0	0	0	0	0	0	0	0	0
PB-CalciumSilicate-Sheet	1895,04	1,03776E-05	0,492936	2,69592	0,165816	3113,28	27297,6	63,87864	1,01655E-07	0,01097544	0,0454584	0,01058064	4,6812
PB-Plastboard-Sheet-AluminiumVaporBarrier	30,69767442	5,5814E-06	0,014511628	0,19255814	0,016465116	189,7674419	530,2325581	392,5395349	3,23721E-06	0,005469767	0,029581395	0,003767442	9,513767442
PB-Plastboard-Sheet-StandardAzero	0	0	0	0	0	0	0	0	0	0	0	0	0
PB-Plastboard-Sheet-FireproofFzero	0	0	0	0	0	0	0	0	0	0	0	0	0

Stone (pietra) "SN" – Parametro "Life Cycle Assessment"	Product Stage							Construction Process Stage					
	GWP (A1-A2-A3)	ODP (A1-A2-A3)	EP (A1-A2-A3)	AP (A1-A2-A3)	POCP (A1-A2-A3)	PERE (A1-A2-A3)	PENRE (A1-A2-A3)	GWP (A4-A5)	ODP (A4-A5)	EP (A4-A5)	AP (A4-A5)	POCP (A4-A5)	PERE (A4-A5)
SN-Stone-WallTile	0	0	0	0	0	0	0	0	0	0	0	0	0
SN-Stone-MixStoneTile	0	0	0	0	0	0	0	0	0	0	0	0	0



STEP 1: INPUT

The object of the study is the external opaque envelope (thus excluding windows) of a multi-storey student residence model floorplan, that will be located in Bologna (Italy). The building structure is a reinforced concrete frame, and the external walls are mostly composed by plasterboard structures insulated with different types of Rockwool panels, enclosed in calcium-silicate sheets and finished with skim-coat layers.

The external envelope has been designed in compliance with the Italian regulation on buildings thermal performance: D.M. 26.06.2015.

The BIM model of the building, at the time of the study, reached the LOD 300, hence including the definitive configuration of the envelope stratigraphy (Fig. 3).

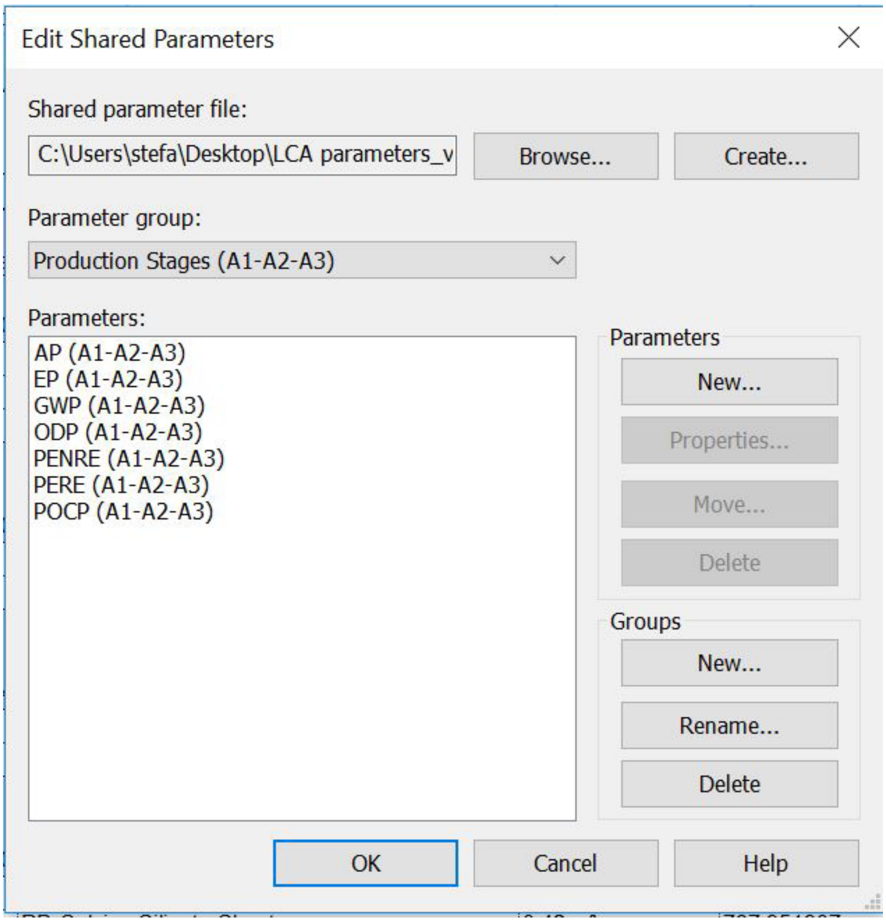
With Autodesk Revit, it was possible to compute the exact quantities of the building materials generating a "wall schedule".

For the quantification of the environmental impacts, specific and local Environmental Product Declarations (EPD) EN 15804 compliant have been collected, thus assuming the consistency with the European context and with the latest environmental management standards. When the right EPD was not available, generic LCA databases (EN 15978 compliant) were used as a secondary data source.

Figure 3: 3D view of the case-study BIM model (designed with Autodesk Revit)
Figure 4: Portion of the spreadsheet containing materials environmental impacts

Eventually, a structured spreadsheet (Fig. 4) containing all the classified materials and products environmental impacts information has been produces following robust classification rules such as:

- organizing all the buildings materials per category and per type;
- codifying and indexing each material with specific type mark considering the previous organization;
- defining a number of columns equal to the number of environmental indicators included in the analysis for each Life Cycle phase considered for a total of 21[1] variables;
- assigning unique tags to each column in order not to create ambiguities with the Revit model codification;



STEP 2: ANALYSIS

The first part of the LCA analysis consisted in the generation, within the Revit file, of a number of custom parameters able to contain the environmental information to embody in the BIM model.
This was accomplished through the creation of specific "shared parameters" (Fig. 5) to associate with the project materials for a total of 21 (One for each indicator for all the Life Cycle phases).

The most delicate part of the analysis, besides, regarded the elaboration of a script through the visual programming tool Autodesk Dynamo, in order to relate the environmental information contained in the spreadsheet to the BIM model parameters, specifically customized to host such data.
The script (Fig. 6, 7) has been developed to accomplish the following task:

- Detecting the spreadsheet within a defined directory;

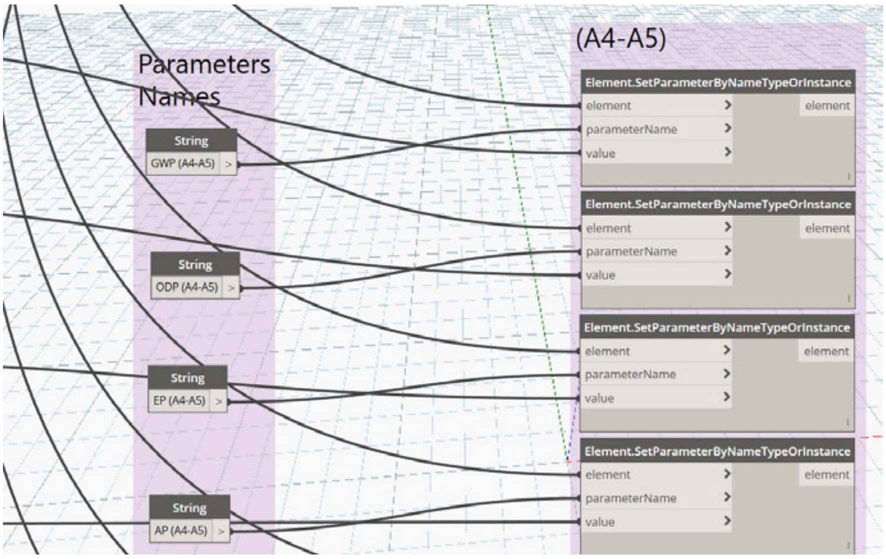
Figure 5: Autodesk Revit shared parameters for the environmental indicators
Figure 6: Autodesk Dynamo script view
[1] The phases considered are three as the A1-A2-A3 and the A4-A5 phases have been aggregate.

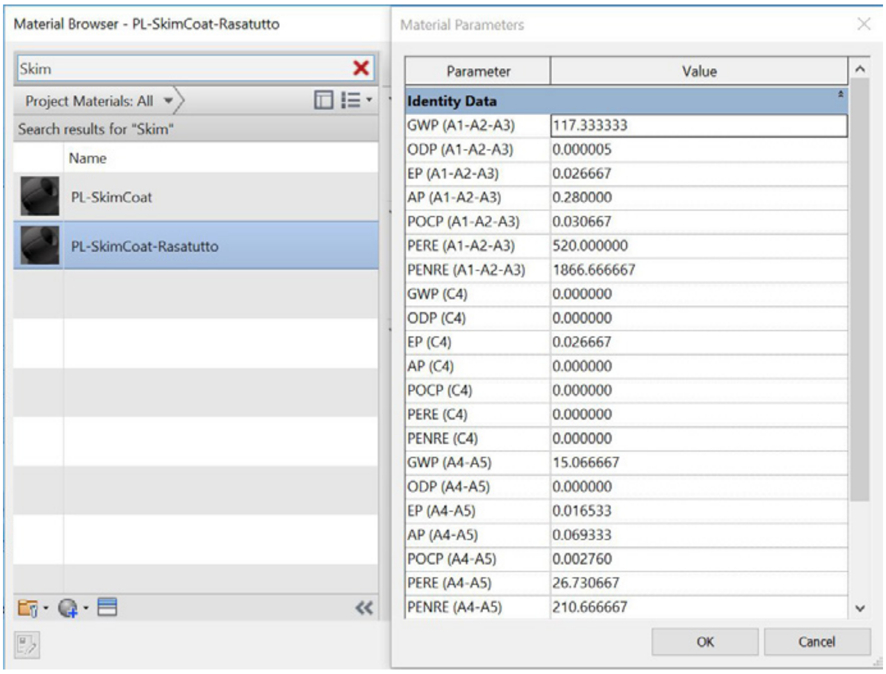
- Reading the content of the cells per column (excluding the headers) at specified positions (indexes) in the spreadsheet;
- Creating lists of elements filled with the content of the cells;
- Recognizing the Revit materials listed in the spreadsheet file with the same designation;
- Recognizing the Revit parameters (shared parameters) listed in the spreadsheet file with the same designation;
- Assigning the lists content incorporating the spreadsheet data, to Revit detected parameters for each specific material.
- An example of the correct run of the script for a material is shown in figure 8.

At this point it was possible to define specific schedules in Revit, in order to visualize the overall environmental impacts, organized per indicator and life cycle phase and sorted per singular material and per aggregate components. Revit schedules, actually, act as simplified spreadsheet, allowing to run easy operation between the cells. This attribute enabled the creation of other custom parameters intended to calculate the LCA outcomes by multiplying the unitary impacts for the actual materials quantities (Fig. 9, 10). Also the grand total of each impact indicator was calculated through the Revit schedules.

STEP 3: OUTPUT

The application of a custom script with a Visual Programming tool such as Autodesk Dynamo in order to interrelate data contained in external spreadsheet with the BIM model elements, permits a full customization of the LCA analysis depending on the goal. It can be employed for design purposes in order to compare and select the materials with the lower environmental loads or it can be used to fulfil the requirements of those Sustainability Rating Tools including LCA credits, such as LEED,





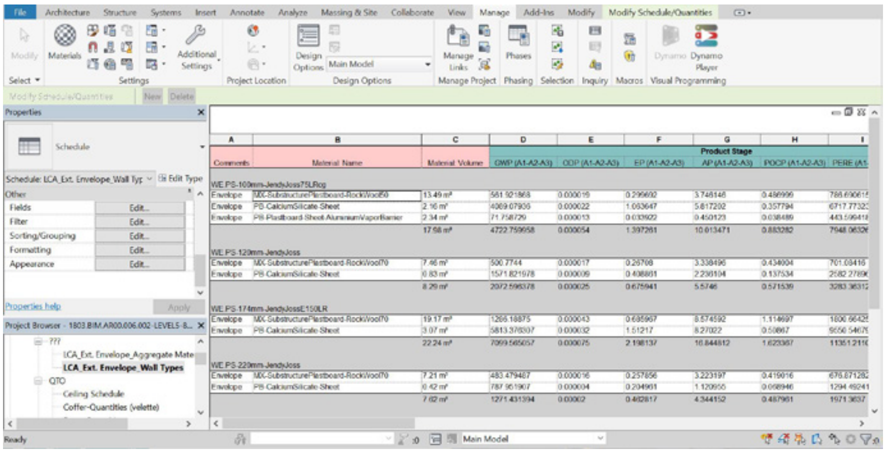
Parameter	Value
Identity Data	
GWP (A1-A2-A3)	117.333333
ODP (A1-A2-A3)	0.000005
EP (A1-A2-A3)	0.026667
AP (A1-A2-A3)	0.280000
POCP (A1-A2-A3)	0.030667
PERE (A1-A2-A3)	520.000000
PENRE (A1-A2-A3)	1866.666667
GWP (C4)	0.000000
ODP (C4)	0.000000
EP (C4)	0.026667
AP (C4)	0.000000
POCP (C4)	0.000000
PERE (C4)	0.000000
PENRE (C4)	0.000000
GWP (A4-A5)	15.066667
ODP (A4-A5)	0.000000
EP (A4-A5)	0.016533
AP (A4-A5)	0.069333
POCP (A4-A5)	0.002760
PERE (A4-A5)	26.730667
PENRE (A4-A5)	210.666667

Figure 7: Portion of the script showing the nodes for assigning the values to the parameters
Figure 8: Filled parameters with LCA data for a material in Revit

DGNB or Green Star.
The schedules are customizable, allowing practitioners to visualize the information in the preferred way depending on the goal of the analysis.
Being a pilot study, the workflow still suffers from complexity in running some step, as it requires manual data entry for the spreadsheet and the manual creation of custom parameters in Revit to host the external data.
Further development could boost the convenience of such an approach, leading to innovative, comprehensive and reliable applications.

DISCUSSION

One of the crucial task of integrating LCA and BIM, is obtaining a convenient decision-making method suitable for the designers on a day-to-day basis without having a particular LCA expertise (Antón and Diaz, 2014). Performing LCA applications with reasonable effort is an ambition to provide design guidance while monitoring the consequences of design decisions (Röck et al., 2018).
Currently, several assessment tools for construction process are available and can be considered a reliable opportunity especially for the easy access provided to several environmental impact databases but, when data incompatibility between different tools occurs, they might not allow universal evaluations (Antón and Diaz, 2014), resulting in a time-consuming format conversion (Lee et al. (2015) with the risk of hindering the possibility of fair comparisons between building materials and products as well as between different design options.
In literature, it is likely to find a number of possible solutions in order to conduct reliable and, within certain circumstances, comparable assessments. In the majority of cases, these solutions imply simplified methods that facilitate data collection and analysis completion.
The use of BIM is spreading rapidly and, for designers and decision makers, this technology can represent a valid means to facilitate LCA analysis at different scales.
Even if at early design stages BIM models usually reach only a low Level of Development (LOD) thus not providing sufficient data to be used in a comprehensive LCA (Peng, 2016), as suggested by Röck et al., (2018), aggregating the environmental database at a building element level can allow to conduct reliable LCA also at initial phases.
Moreover, the capacity of BIM tools to easily produce (and provide access to) the bill of materials quantities, allows a continuous real-time update of the LCA evaluation, as the project acquires a greater level of details, hence a higher LOD.
In line with other experiences found in literature (Shadram and Mukkavaara, 2018) endorsing the use of visual scripting tools, the proposed workflow employed Autodesk Dynamo for the integration between the BIM software and the external data sources, thus allowing progressive assessment updates.
Other key aspects considered in order to obtain comparable assessments, were: setting a number of ground rules and conventions to adopt, both in the spreadsheet structure and in the BIM



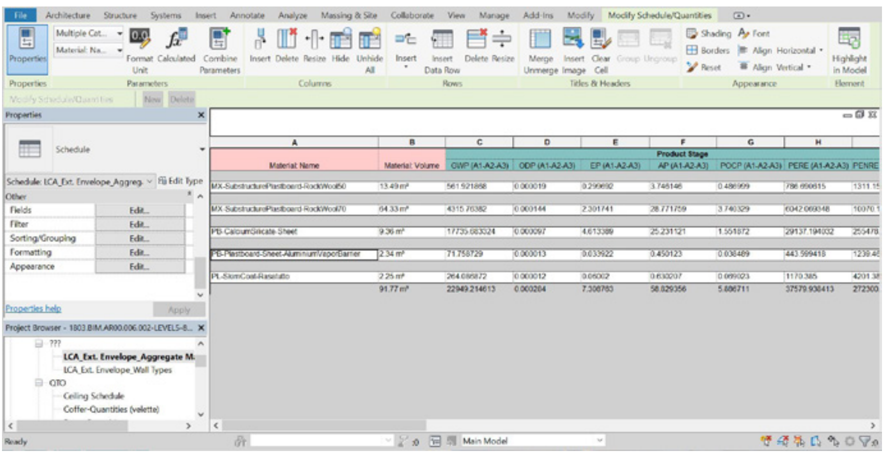


Figure 9: Portion of Revit schedule indicating the LCA outputs for the external envelope wall types
Figure 10: Portion of Revit schedule indicating the LCA outputs for the materials composing the external envelope

tool, basing on the goal and scope of the analysis, and referring to the same standards and regulations depending on the context of the study.

The benefit of performing such an integration employing the proposed method are:

- easy access to the actual quantities and attributes of construction materials and products of the building, thus avoiding manual data entry;
- autonomy of adapting the assessment variables (e.g. study boundaries, environmental indicators) to different analysis scopes, depending on personal expertise and evaluation goals;
- opportunity of comparing different design alternatives, especially with regard to materials and products, resulting in an effective decision-making tool;
- capacity of real-time assessment as the project level of detail evolves: from the early design stages to the conclusive ones, without re-importing the BIM model into external LCA platform every time the model changes;
- opportunity of taking advantage of a structured spreadsheet for materials and product that can be updated with new elements and environmental information and, therefore, it can be re-employed in further analysis;

This paper also evidences certain inconveniencies such as:

- producing a spreadsheet implies a robust structure in naming and classifying materials and environmental impacts, resulting in an accurate but time-consuming manual data entry since is still not achievable to obtain an automatic data import from EPDs or other LCA databases into the BIM models;
- collecting reliable data from certified sources, such as EPDs, is still a delicate step since it depends on the availability of data for all the project materials and products;
- the accuracy in performing the LCA and the representativeness of the outcomes, depends greatly on the quality of the BIM model;
- the issue of calculating and automatically including aspects such as transportation information, construction techniques, materials and product maintenance, is still problematic due to the different features and locations of each project;

This sample workflow, even if applied on just one case study does not limit the validation of the method, since the ground procedures for the environmental data processing and its integration into the BIM environment do not depend on different buildings design process and different buildings typologies (Röck et al., 2018).

CONCLUSION

This paper proposed a sample workflow of a simplified BIM-LCA integration through the employment of a Visual Scripting tool, addressing some of the requirements expressed in the literature with reference to environmental assessment at initial stages and simplification approaches to LCA, aiming at providing a reliable overview of different materials and products alternatives.

Such an approach has shown to imply some benefits in performing LCA analysis within a BIM environment, with respect to operational feasibility and economic convenience, as well as some drawbacks resulting from unresolved LCA issues and methodological limitations.

In line with other experiences found in literature, dealing with existing methods and tools for effectively integrate BIM and LCA analysis (Antón and Diaz, 2014), this paper recognize that further developments are required in this field.

Interoperability between BIM models and LCA tools needs improvements and data exchange for automatic association of each building material and products with the unit processes during the life cycle is still a relevant challenge (Soust-Verdaguer et al., 2016).

Building Information Modelling (BIM) is providing a great improvement in the overall information management regarding every phase of the building process, fostering the achievement of better project performance and quality. Further developing the interoperability between BIM designs and LCA analysis, can concur to the improvement and the ease of integrated design which can be seen as a key factor in achieving sustainability (Antón and Diaz, 2014).

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Sara Marchello

11

Asbestos Hazards Analysis in Construction Projects With the Fault Tree Analysis and the Failure Mode and Effect Analysis

KEYWORDS: HEALTH AND SAFETY AT WORK, RISK ANALYSIS, ASBESTOS RISK, FAULT TREE ANALYSIS, FAILURE MODE AND EFFECT ANALYSIS.

The Italian construction sector suffered more than the other industrial sector the negative effects of the world economic crisis. A consequence has been a change in its organization concerning labour and managent on the health and safety issues. Evidence of this can be found in an increase of fatal accidents and occupational diseases. In particular occupational diseases became a health concern in construction. The aim of the presented research work is to assess the hazard of asbestos fibres inhalation due to decommissing of old industrial promises with roofing of asbestos. The developed approach starts from a probabilistic assessment of the risk, using the Risk Analysis tools, the Fault Tree Analysis (FTA) and the Failure Mode and Effect Analysis (FMEA). Risk assessment through the FTA is based on a backward approach: it starts from the malfunction of the system, called Top Event, in order to look for the triggering causes (events); on the contrary, the FMEA analysis is based on a forward approach: they start from a set of events and go on in order to analyse what kind of malfunctioning these can generate in the system. Both the FTA and the FMEA are applied to three approved decontamination techniques (encapsulation, confinement and removal), and for each of them operational phases, equipment, building products and PPE (Personal Protective Equipment) are evaluated highlighting the procedures needed to operate in complete safety.
With this approach the main factors that contribute to the increase of the risk of asbestos fibres inhalation are detected: preliminary analysis and assessment of the state of building decay, the use and maintence of PPE and machinery, and the supervision during main working phases.

INTRODUCTION

The construction sector has suffered more than the others from the negative effects of the economic crisis, ISTAT data (ISTAT, 2017) show that since 2008 a total of 800.000 job positions have been lost. In recent years, the building site has changed profoundly and as a result the organization of work within it has changed.

After some years of reduction of both accidents and fatal accidents, we are witnessing a worrying increase in occupational diseases because of less safety at work. In the five-year period 2013 - 2017, according to the INAIL observatory data, (INAIL, 2013 - 2017) an increase of 20% of the diseases of suspected professional nature is found. The occupational diseases caused by exposure to asbestos is the aim of this research work. The fifth RENAM (National registry of mesotheliomas) report published by INAIL reports the data related to Mesothelioma cases detected by the Regional Operative Centers. From the data examined and related only to those affected by professional causes, the sector most affected by this dramatic record is that of construction with 15.2% of cases. About occupational cancers, construction workers are the most exposed to lung cancer; precisely, they are 50% more likely to develop lung cancer than all other workers.

The widespread presence of Asbestos Cement Materials (MCA) in the construction industry determines a risk of exposure to asbestos, especially for those who carry out building renovations, even if decontamination is normally carried out by specialists with dedicated training. The decontamination and removal of slabs of cement - asbestos used in buildings for the roofing is a typical case of building intervention where laborers exposed to asbestos. Building operation involves a specific risk of falling, with or without breaking the slabs, and dispersion of asbestos fibers, for these reasons suitable temporary works must be created to protect against the risk of falling and workers must be provided with suitable means of protection of respiratory tract and protective clothing.

The aim of the present study consists in the analysis and assessment of risks in the remediation operations of a cement-asbestos roof, specifically the risk of inhalation of asbestos fibers. We intend to proceed with a probabilistic risk assessment, using the tools of FTA - Fault Tree Analysis, based on a backward approach, and the FMEA - Failure Mode and Effect Analysis, based on a forward-type approach, which represent systems of innovative analysis for the building sector, but already proven in other areas, for example in the aerospace missions of NASA, in the robotics, chemical and automobile industries. The analysis is carried out on the three techniques of remediation (encapsulation, confinement and removal) analyzing for each the operations to be performed, the materials and the products to be used, the individual protection devices to wear carefully assessing what needs to be done to operate in complete safety.

ASBESTOS HAZARDS

Asbestos is a natural mineral with a microcrystalline structure and a fibrous appearance. The fibrous structure gives the asbestos a remarkable mechanical resistance and a high degree of flexibility; it resists very well to fire, heat, the action of chemical and biological agents, abrasion and thermal and mechanical wear, it also has sound-absorbing and heat-insulating properties and easily binds with building materials (lime, gypsum) and cement) and some polymers (rubber, PVC). The characteristics of the material and the low cost have favored a wide use in the sectors of industry, construction and transport. If, on the one hand, the fibrous structure has brought asbestos to have "positive" characteristics in its flexibility of use, on the other hand these fibers of which it is composed have the characteristic to divide longitudinally, whereby the material maintains the fibrous appearance up to the size of a few hundredths of a micron and for this reason it is so dangerous because, if inhaled, it can penetrate deep into the pulmonary alveoli and be carcinogenic.
With the issue of law n. 257/1992 - which prohibits the extraction, importation, exportation, marketing and production of asbestos - has started an important remediation work. The importance of planning and implementing the removal of materials containing asbestos was also recognized through the establishment of incentives by the Government.
Law 257 of 27 March 1992 is considered the Framework Law on asbestos as it was intended to regulate the process of asbestos disposal by defining precise criteria. It provides for the issuance of a series of decrees by the Ministry of health of a technical nature through which the intervention criteria have been established, the operating procedures to be adopted for the handling of materials containing asbestos, the methods for assessing the risk and safety procedures to be taken in materials removal work.
The first of these ministerial decrees is D. M. 6 September 1994 "Regulations and technical methods of application of art. 6, paragraph 3, and of the art. 12, paragraph 2, of the law March 27, 1992, n. 257, concerning the cessation of the use of asbestos ". The decree dictates the safety measures to be followed during the remediation interventions, the criteria and the limit values for the restoration of the environments after the remediation and describes the technical methods of custody of the materials and the operational procedures for the remediation of the same.
For the removal and maintenance of materials containing asbestos, the specific provisions relating to temporary or mobile construction sites provided for by Title IV of Legislative Decree 81/2008, in addition to those laid down by Chapter III of Title IX, concerning the " Protection of risks related to asbestos exposure ".
Remediation can be achieved by three techniques:

- encapsulation - treatment of the plates with products that cover the material preventing the release of the fibers;
- confinement - installation of a new roof over the existing one in cement - asbestos;
- removal-elimination and consequent disposal of the material containing asbestos.

Each of these methods of remediation, if not carried out correctly and without the appropriate protection devices, can pose serious risks to the health of workers.
Legislative Decree 81/2008 provides for an official communication to the Local Health Authority responsible for the territory in case of any activity concerning materials containing asbestos:

- notification in case of encapsulation or confinement - art. 250 of Legislative Decree 81/08
- in case of removal, a work plan is required - art. 256 of Legislative Decree 81/08

These mandatory communications are preventive, ie they concern activities that have not yet been carried out.
To arrive at an assessment on the need and urgency of remediation operations for asbestos-cement roofing (CA), algorithms have been developed over time to obtain objective and reproducible results. Examples of algorithms currently in use are the following:

- Index EPA
- Index FERRIS
- Index VERSAR
- AMLETO – Model for the assessment of the state of the CA roofing of the Emilia Romagna / Tuscany / Lombardy / Abruzzo Regions.

AMLETO is an algorithm based on a two-dimensional model that has the purpose of providing an operative tool to obtain indications on the actions that must be taken towards cement materials containing "exposed" asbestos.
The indicators considered refer to two parameter families:

- The context in which the building is inserted
- The state of conservation of the material

The calculation is made by adding the scores assigned to the parameters that describe the context in which the coverage is located, of which the total is shown on the abscissa axis of the graph, and the scores attributed to the parameters that describe the state of conservation of the coverage, taking account of the score on the worst side, whose total is shown on the axis of the chart's ordinates. The pair of values thus obtained identifies a point on the Cartesian plane included in one of the four areas in which the graph is subdivided and to which the different actions to be undertaken correspond.

METHODS PROPOSED FOR ANALYSIS AND RISKS ASSESSMENT

An effective management of health and safety in the workplace arises from a preventive and accurate analysis, assessment and subsequent risk management. Hence the need to have methodologies and support tools that, through the acquisition and management of data, allow the recognition and characterization of the risks that we intend to analyze, evaluate and manage in scenarios and operational contexts. With this in mind, INAIL, the National Institute for Workplace Accident Insurance, through the Department of Technological Innovations and Safety of Plants, Products and Anthropic Settlements, is committed to analyze the risk assessment process, to provide models of simplified and standardized risk analysis and management and organizational models dedicated to small business types where the risk underestimation could be greater, identifying the weakest phases (materials, procedures, organization), and developing subsidized procedures derived from risk analysis methods, FMEA and FTA, already used in reality of significant size and characterized by greater risks. The research activity is oriented to the development of experimental procedures to verify the structural integrity and reliability of components or elements of pressure equipment and lifting systems, based on failure analysis and fracture mechanics. With this study we intend to proceed with a probabilistic risk assessment, using the Risk Analysis tools.
To evaluate the risk of a system two approaches can be used:

- Forward analysis: we start from a set of events and we proceed forward to analyze what kind of malfunctioning they can generate in the system. It is therefore a preventive study aimed at eliminating critical system issues before the incident occurs. The analysis methods of this type are as follows:
    - IDEF - Integration Definition Language
    - SHELL - Software (norme), Hardware (strumenti), Environment (ambiente), Livewire (persona in attività)
    - FMEA – Failure Mode and Effect Analysis

- Backward analysis: it starts from the malfunctioning of the system and we go to look for the possible triggering causes (events). The analysis methods of this type are as follows:
    - IR – Incident Reporting
    - RCA – Root Causes Analysis
    - FTA – Fault Tree Analysis

Regardless of the methodology used, the priority conditions for the correct implementation of a Risk Analysis system are the correct initial classification of the potential error and the correct decomposition of the process for the identification of the microactivity in which the error resides.
In this paper, we choose to use the following Risk Analysis tools:

- Fault Tree Analysis (FTA) o Albero dei guasti
- Failure Mode and Effect Analysis (FMEA) o Analisi dei modi e degli effetti dei guasti.

FTA - FAULT TREE ANALYSIS

The Fault Tree Analysis (FTA) is a deductive method, it starts from an undesired event to determine (or rather deduce) the necessary and sufficient causes in a systematic way, through a backward procedure for successive steps.
The Fault Tree Analysis was developed for the first time in 1962 at the Bell Laboratories of HA Watson, as part of a contract of the "US Air Force Ballistics Systems Division" to evaluate the "Minuteman Launch Control System". Dave Haasl, then at the Boeing Company, recognized the value of this instrument and, in 1963-1964, led a team in the application of the FTA for an entire "Minuteman Missile System" (ie it extended the scope of the analysis to the universal system, not just to the control system). Other compartments within the same company noted the results that this program was able to provide and began to use the FTA also in the design of civilian aircraft. In 1965 Boeing and the University of Washington promoted the first Security Systems Conference, which saw many FTA magazines present, marking the beginning of its worldwide release.
Failure tree analysis was, in the mid-seventies, one of the most popular probabilistic techniques in PRA - Probabilistic Risk Assessment. Thus, at the beginning of the Apollo project, it was used to evaluate the probability of success in sending astronauts to the Moon and their return to Earth in good condition. The result was a probability of success of the mission that was unacceptably low, against the decidedly positive outcome of the real mission. This result has therefore discouraged NASA from using this type of analysis until the 1986 Space Shuttle Challenger accident. After that sad episode, NASA decided again to rely on the use of fault analysis (FTA) and effects analysis (FMEA) together with other qualitative methods for the evaluation of the safety system.
In addition, the FTA has earned its place over the years as a tool for safety assessment, risk assessment, investigation of accidents and reliability. The number of tree diagrams created over time shows that the interest in the FTA is not declined, but currently remains constant over time. As with any new discovery, there have been criticisms over the years, but the unequivocal benefits and strength of the FTA have discredited the arguments against it. Thus the FTA has become today an instrument recognized and used internationally.
The creation of a FTA involves the following steps:

1. Identify the objective of the FTA;
2. Define the FTA top event;
3. Define the purpose of the FTA;
4. Define the resolution of the FTA;
5. Define the basic rules of the FTA;
6. Building the FT;
7. Evaluate the FT;
8. Interpret and present the results.

The basic concept that drives the development of the FT is "thinking small". In fact, starting from the top event defined, it is necessary to identify only those causes, necessary and sufficient, which are immediately preceding. That is, you should not jump directly to the root causes, but you have to proceed for small successive steps through the causes immediately preceding the event analyzed. This backward procedure, only after several steps, will end with the basic causes that constitute the resolution of the analysis.
The FT is presented as a graphical reduction of the logical relationships between fault events that, with their occurrence, lead to the creation of an initiator event (or top event). The events that can be found in one of these diagrams can be grouped into 5 categories: basic event, intermediate event, top event, undeveloped event and conditioning event. The events are located in the tree with a precise hierarchical order, defined by the structure of the system and the logic of correlation. They are also well identifiable by a conventional symbology, as are the logical gates that connect events to one another. There are two main types of logical gates: the OR-gate and the AND-gate. All other types are subspecies of these two.

Qualitative evaluation of the fault tree

Once the fault tree has been drawn, its characteristics can be evaluated using the Boolean equations. The events correspond to the variables and the logical gates to the operations; the OR-Gate, representing the union between the events, corresponds to the sum and the AND-Gate, representing the intersection between the events, corresponds to the product.

This defines the Top Event in terms of Minimal Cut Sets, or the smallest combination of events that, if all verified, cause the occurrence of the Top Event.

$$D = A \cdot (B + C)$$

Quantitative evaluation of the top event

When the Top Event equation is expressed in terms of Minimal Cut Sets, the probability of occurrence of the Top Event can be approximated as the sum of the probabilities of each minimal cut set.

$$P(TE) = \sum_{i=1}^{n} P(Mi)$$

$$P(D) = P(A) \cdot P(B+C)$$

The probability of occurrence of an event is defined by the product between the failure rate (λ) and the relevant time interval (t).

$$P = \lambda \cdot t$$

The failure rate corresponds to the frequency of occurrence of an event, defined as the ratio between the number of injuries and the number of hours worked. The relevant time interval considered corresponds to the duration of the work in hours, relative to the specific construction site.

FMEA - FAILURE MODE AND EFFECT ANALYSIS

Failure Mode and Effect Analysis is a technique for assessing the reliability of a project by considering potential failures and their effects on the system. It aims to define corrective actions to minimize the effects of failure modes. Generally, but not necessarily, the analysis is performed in advance and is therefore based on theoretical and non-experimental considerations. FMEA analysis can also be used as a basis for the evaluation of a redesign, a proposed replacement during manufacturing, assembly, installation and control phases.
The FMEA originated in the United States on November 9, 1949, with the introduction of the military procedure "MIL-P-1629" (Procedures for Permissioning to Failure Mode, Effects and Criticality Analysis), with the aim of classifying failures based on the impact on the success of the mission and on the safety of personnel and equipment. In the 60s it was applied for Apollo space missions.
Subsequently, in the 80s, it was used by the automaker Ford to reduce the risks on a car model, the Pinto; this car had a repetitive problem of breaking the tank which caused fires in case of accidents. In 1994, Chrysler, Ford and General Motors, sponsored by the USCAR (United States Council for Automotive Research), formalized a common procedure for the implementation of the FMEA.
To date, the use of the FMEA is foreseen by various quality management systems. This analysis is one of the main components of the PPAP (Production Part Approval Process) and is also applied within the Six Sigma

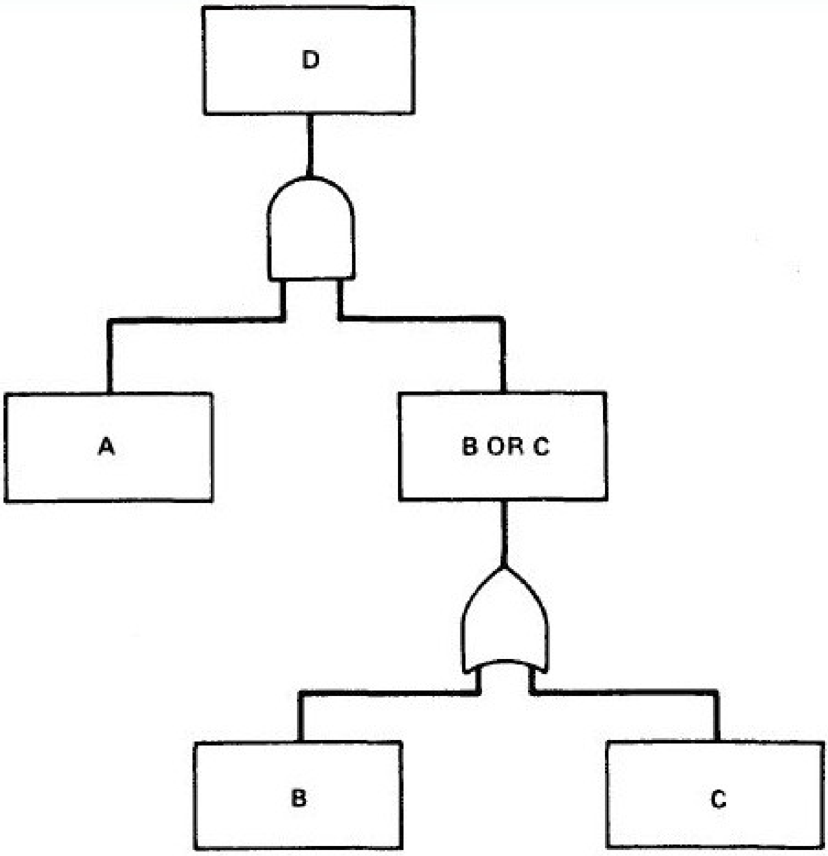


Figure 1: Structure of the fault tree for the equation D = A · (B + C).

methodology, a quality management program based on the control of the average square deviation (indicated with the Greek letter sigma) that has the aim of bringing the quality of a product or service to a certain level, particularly favorable to the consumer.

Analysis consists in identifying the fault modes, an element or process of the system, and for each failure mode the possible effects and all potential causes are determined.

Once these aspects have been defined, for each identified cause, the Risk Priority Index is calculated, defined by the product of three factors:

O – Occurrence – Probabilityof occurring the cause.

S– Severity of the potential effect.

D– Detectability of the cause, it is the probability of identifying the cause through the controls normally used in the process.

These indices are evaluated with a scale from 1 to 10, where 1 represents the minimum risk and 10 the maximum. Thus, a value of Risk Priority Number (RPN) between 1 and 1000 is obtained, which highlights the seriousness of the problem to establish a priority of intervention; the problems with major RPN will be clearly addressed, for which corrective actions must be decided to allow greater control of the cases examined.

To reduce Occurrence factorit acts on prevention, through adequate training and operational organization; to reduce the Severity factor, on the other hand, protection is applied, and therefore using PPE and DPC. Preventive controls can be made to decrease the index of Detectability.

FMEA can be repeated following the improvement actions to check if the values of the RPN index have decreased. Therefore, a new hypothetical RPN index value is obtained to estimate the effect of the interventions applied and to highlight the items on which to intervene subsequently.

FTA AND FMEA FOR HAZARD ASSESSMENT OF ASBESTOS ROOFING REMOVAL PROCEDURES: CASE STUDY

The developed approach involves a probabilistic risk assessment, using the tools of the FTA - Fault Tree Analysis and the FMEA - Failure Mode and Effect Analysis. The analysis is carried out on the three remediation techniques, analyzing for each the operations to be carried out, the products to be used, the individual protection devices to wear and the operation work procedures for safety.

To carry out the analysis, a work carried out by a company of Bologna, leader in the field of decontamination materials containing asbestos, was examinated on an Eternit roof of an agricultural building located in Minerbio, in the province from Bologna.

For the purposes of this study the INAIL, ISTAT and Confartigianato reports, specific of construction sector, were consulted to obtain values of failure rate and relevant time interval. The injury is the result of succession of several different events connected to each other, whose study represents an important step in the identification of main risk factors and consequent development of effective prevention strategies. Knowing how accidents occurred is the basis for a correct prevention and protection action, but a homogeneous information system must be used for recording data related to accidents in order to make them comparable. Since the 1990s, this need has led to the development of a project called ESAW, an acronym for European Statistic of Accidents at Work, created with the aim of using recognized and defined codes at European level for the cataloging of accidents. INAIL through the ESAW variables codifies accident reports: causes and circumstances reported in the individual complaints are traced to codes and constitute an indispensable database for preventative analysis. Within its database, which can be consulted online, INAIL provides data on injuries reported for each type of activity and it is possible to filter the search through the variables of specific interest. From the combination of the variables we obtained the number of

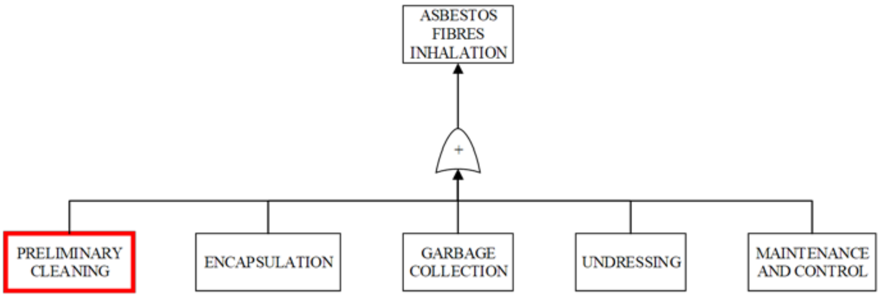
accidents for the purposes of research. On the basis of INAIL database, for the purposes of a more rapid and complete identification of injuries, a database was prepared containing all the possible events that cause the injury and the material agents involved in such events. This elaboration was carried out for the construction sector, the area of interest for this study. From the combination of deviation, or rather the action that led to the occurrence of the accident, and the material agent involved in the deviation, the number of accidents of interest for the purposes of probabilistic calculations is obtained.
Instead the number of work hours was obtained from the Confartigianato site, in the construction report based on ISTAT statistics.

Asbestos slabs remediation through encapsulation

The remediation of an Eternit roofing with the encapsulation technique involves the following operational steps:

- Preliminary assessment of the coverage status;
- Site construction;
- Cleaning and preparation of the support;
- Encapsulation;
- Garbage collection;
- Undressing;
- Maintenance and control.

Let's now look at the application of the Fault Tree Analysis to remediation by encapsulation.



The Top Event is represented by the risk that is being analyzed, that is the inhalation of the asbestos fibers, which represents the failure of the process. As the first intermediate events, the operating phases during which the Top Event could occur, and the first logical gate used is that of the OR-Gate, since we want to impose that the TE occurs if even one of the inputs is occur. All inputs are secondary failures of a system component, so they must be further developed through another OR-Gate.
For example, the "Preliminary cleaning" event is developed. The failure during this phase occurs if, for example, a machine-related fault occurs, or if there is a lesion in the cover, or if there is a fault related to the PPE.
For example, the event is developed to the machinery. It can occur if there is a malfunction or if it is misused.

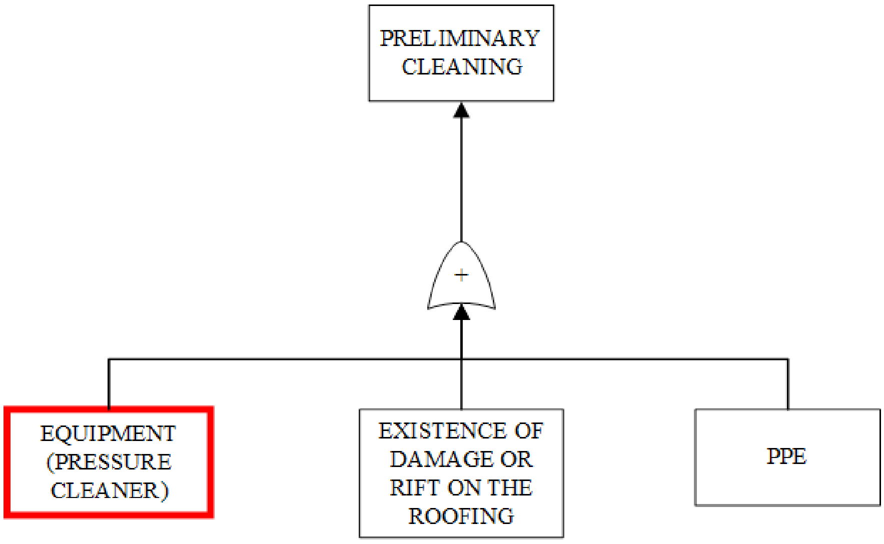
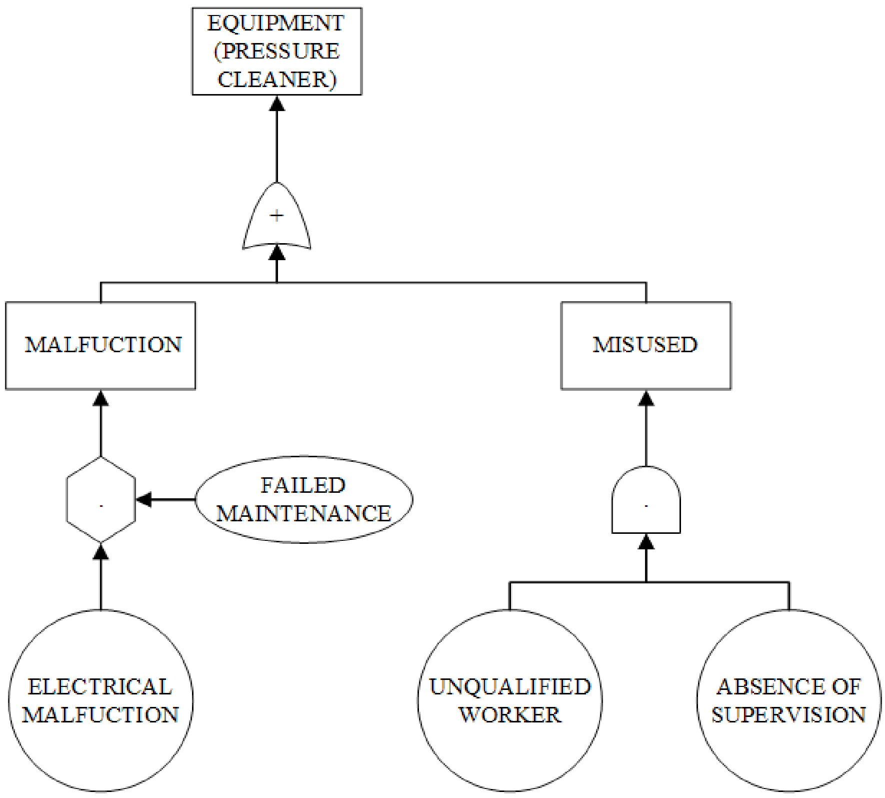
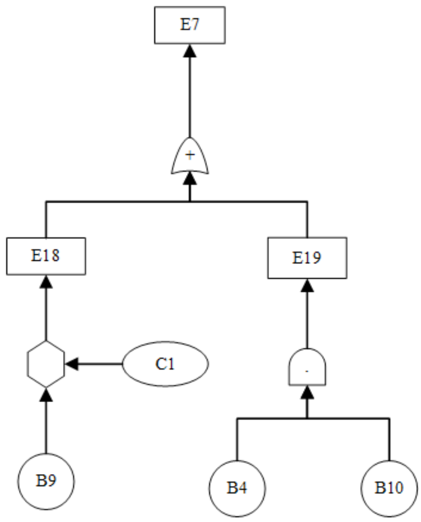


Figure 2: Phase 1 of construction of the FT.
Figure 3: Phase 2 of the construction of the FT.





The malfunction can in turn be caused by an electrical fault, but this failure could be avoided through preventive maintenance or control. Therefore the "Failed maintenance" event becomes a condition to be imposed for the occurrence of the malfunction. On the other hand, the event "Misused" can happen if the worker, for example, has not received adequate training and if there is no control during the work, otherwise the error could be noticed. This proceeds with the construction of the fault tree until the causes are all represented by basic events that can not be further developed.
Once the Fault Tree has been built, in order to proceed with an evaluation of the Top Event, the event descriptions are replaced with the corresponding codes. In the present study the intermediate events were indicated with the letter E, with the B the basic events and with the C the conditioning events.
Then it proceeds with the qualitative evaluation using the Boolean equations,

$$E_7 = E_{18} + E_{19}$$
$$E_{18} = B_9 \cdot C_1$$
$$E_{19} = B_4 \cdot B_{10}$$
$$E_7 = (B_9 \cdot C_1) + (B_4 \cdot B_{10})$$
$$P(E_7) = P(B_9 \cdot C_1) + P(B_4 \cdot B_{10})$$

after that the equation must be solved in terms of probability of occurrence. to have a more concrete vision of the results obtained.For the encapsulation, the probability of inhaling asbestos fibers during the remediation work is 3,66•10-6, so approximately 4 yards per million.
As it can be seen from the graphs, the riskiest phases are "Garbage collection" and "Preliminary cleaning", which affect the TE for 53% and 21% respectively.

As for primary events, the most influential are related to training and control, which are the basis of a safe construction site.
The results have come to light from FTA have been confirmed by Failure Modes and Effects Analysis, indeed the causes with higher RPN are related to preliminary cleaning and collection of waste.
The malfunction can in turn be caused by an electrical fault, but this failure could be avoided through preventive maintenance or control.

Figure 4: Phase 3a of the construction of the FT.
Figure 5: Alternative representation of the FT with the codes.

Therefore the "Failed maintenance" event becomes a condition to be imposed for the occurrence of the malfunction. On the other hand, the event "Misused" can happen if the worker, for example, has not received adequate training and if there is no control during the work, otherwise the error could be noticed. This proceeds with the construction of the fault tree until the causes are all represented by basic events that can not be further developed.

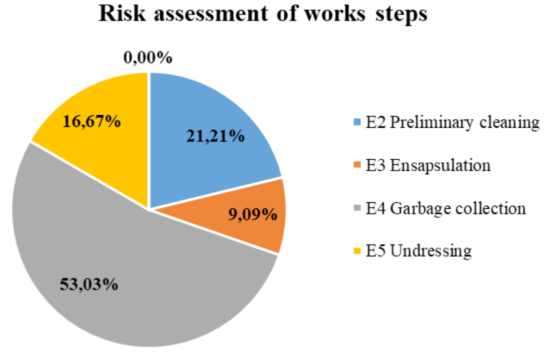
Once the Fault Tree has been built, in order to proceed with an evaluation of the Top Event, the event descriptions are replaced with the corresponding codes. In the present study the intermediate events were indicated with the letter E, with the B the basic events and with the C the conditioning events.

Asbestos slabs remediation through confinement

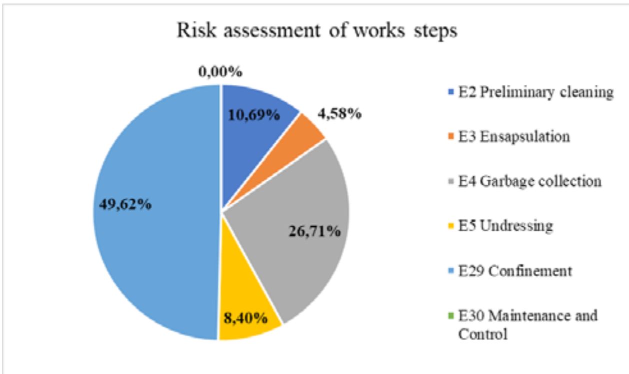
The remediation of an Eternit cover by means of the confinement technique foresees the following operational phases:

- Preliminary assessment of the state of the coverage;
- Site construction;
- Cleaning and preparation of the support;
- Encapsulation;
- Confinement;
- Garbage collection;
- Undressing;
- Over – roofing maintenance.

The same analysis procedure was carried out for the remediation by confinement, where the probability of inhalation of the asbestos fibers is equal to 7,27•10-6, about twice the previous case. In this process, the riskiest phase is precisely the "Confinement" phase of the coverage, which represents about 50% of the total risk and the most influential primary events are "Worker goes down from the basket and walks on the cover is not feasible" and "Improper use of the tools ".



ANALYSIS				ASSESSMENT				SOLUTION				
				PARAMETRI FMEA					PARAMETRI FINALI			
PROCESS STEP/INPUT	POTENTIAL FAILURE MODE	POTENTIAL FAILURE EFFECTS	POTENTIAL CAUSES	OCCURRENCE (O)	SEVERITY (S)	DETECTION (D)	RPN	ACTION RECOMMENDED	OCCURRENCE (O)	SEVERITY (S)	DETECTION (D)	RPN
cleaning with electrical brush	damaged slub	dispersion of asbestos fibres	misused equipment (high pressure cleaner)	3	10	2	60					
			high aggressive cleanser	3	10	2	60					
			already deteriorated roofing	10	10	2	**200**	preliminary ispection and assessment	2	10	2	40
garbages with asbestos in the bags	dispersion of asbestos fibres	contaminated space	not completely closed bags	8	10	8	**640**	training and supervision	2	10	4	80
			not resistant bags	5	10	8	**400**	using high resistant bags	1	10	2	20



Asbestos slabs semediation through removal

The remediation of an Eternit cover using the removal technique involves the following operational steps:

- Preliminary assessment of the state of the roofing;
- Site construction;
- Cleaning and preparation of the support;
- Encapsulation;
- Removal of MCA powders from the eaves;
- Dismantling of Eternit slabs;
- Plate movement;
- Packaging of the removed plates;
- Garbage collection;
- Undressing.

During the remediation through Removal the most risky phase is the "Dismalting of Eternit slabs", as it could be expected, and it represents about 86% of the total risk, equal to 2,93•10-5.

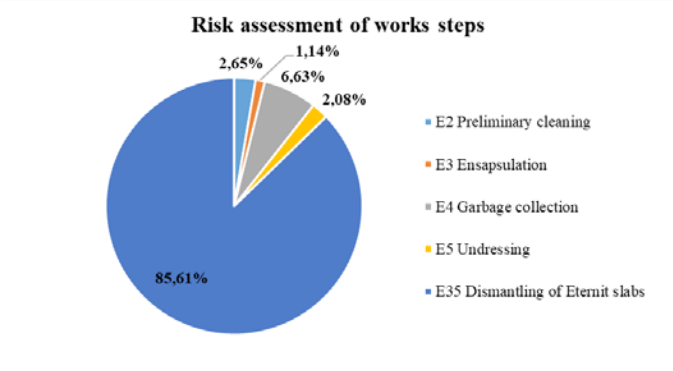
Figure 6: Risk assessment of works steps.
Figure 7: Example of analysis FMEA Encapsulation.
Figure 8: Risk assessment of works steps.

The most influential primary events were found to be linked to a hardly predictable factor: human error.
Comparing the results obtained the remediation through Removal is undoubtedly the riskiest. It must however be considered that the Encapsulation phase is present in all cases, as it represents the basis for carrying out the work, so it was obvious that the Confinement and Removal of the roofing were riskier than the other.

The results of this research reflect the statistical data and the data collected in the literature, in fact the remediation by removal turns out to be the riskiest for the type of processing, having to manipulate the asbestos-cement slabs.

CONCLUSIONS

The analysis and assessment of risk through the application of Fault Tree Analysis and Failure Mode and Effect Analysis techniques is a valid choice to make critical and reasoned choices in order to optimize resources and at the same time ensure a high level of security; these methods allow the analysis of the process to be dealt with in detail, thus allowing a meticulous evaluation of all the possible causes that lead to the occurrence of the accident phenomenon. It is therefore possible to intervene on individual events by making preventive changes.
The joint use of the two techniques leads to an accurate analysis because the FTA method, which represents the most consistent and complex part, allows to reach a definition and quantification of the risk and its causes, while the FMEA method contributes to a better definition of the quantification of the risk and its consequences.
One of the fundamental aspects to take into consideration when doing an analysis of this type is the subjective nature of the risk itself, which leads to obtain different results for the same object under analysis depending on the context, the data and the level of detail, that whoever makes the analysis chooses to take into consideration. Another consideration to make is that the preponderant component is the worker and is associated with the uncertainty of human error, difficult to define in a statistical way. The probability of occurrence of the Top Event, therefore, being the result of a product between probabilities related to multiple variables of human errors, will be influenced by a high degree of uncertainty. The results obtained are useful as indicators of the risk associated with the specific project analyzed, but they are subjective and therefore affected by numerous uncertainties.
To improve the efficiency of FTA and FMEA analysis techniques, a more detailed database collection of the specific processes would be required, thus ensuring the most precise and objective results. For example, for the work done in this study, a database of injuries of companies carrying out remediation work on materials containing asbestos could be useful; in this way the analysis would lead to even more detailed and precise results.
Finally, it is important to underline that, however precise a risk analysis may be, a zero or very small failure rate is almost impossible to obtain because it refers to real situations in which many several factors come into play; interferences are often difficult to predict or keep under control.
The data obtained reflect the statistical data and the data collected in the literature, in fact the remediation by removal turns out to be the riskiest for the type of processing, having to manipulate the asbestos-cement slabs.
It has therefore been shown that the methods of analysis used prove to be effective by returning values that are like reality.



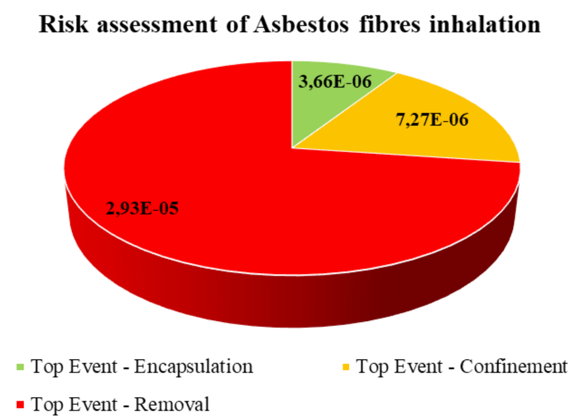


Figure 9: Risk assessment of works steps.
Figure 10: Risk assessment of Asbestos fibres inhalation.

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Simone Garagnani

12

Digital Renovation: BIM for the Built Environment

KEYWORDS: HBIM, Heritage BIM, Cultural heritage, Built domain, historic architecture

The scientific literature related to the adoption of the Building Information Modeling has incredibly grown up in recent years, although it is still lacking of formal and effective general workflows explicitly dedicated to the built domain. The meaning of the term HBIM itself, often misused to outline the digital process applied to existing constructions, is erroneously misconceived, as it is primarily a comparative methodology between digital surveys and their derivative 3D abstractions, not a generic acronym to be used when referring to the whole digitalization of the built environment. The aware acceptance of digital methodologies and procedures for existing buildings (not necessarily monuments or archaeological sites) as well as the BIM lifecycle approach adoption on new constructions, is a strategic decision that, however, needs to be properly evaluated when considering the optimal workflows to be preferred from time to time. Also, the intervention on consolidated buildings or facilities has to follow a path made of procedures and intertwined digital models, following patterns of increasing complexity. The two elements, process and models, are deeply intertwined even though the former is still not explicited for the latter, due to a standardization at an embryonic stage and, perhaps, seriously confused by someone with politics. From the software perspective, interoperable file formats and data structures considering information for restorations and renovations are in development all over the European countries. Thus, this paper delves into considerations, implications and effects of a possible mature and aware adoption of IT and digital technologies for restoration, renovation and documentation design intents. Introducing some reflections whose outcomes are represented by the application of novel dedicated strategies fitted on advanced equipment to better understand the existing realm (proximity TLS and UAVs surveys, use of sensors, etc.), the paper brings into the discussion some future scenarios on the uses of more and more interconnected semantic technologies, proposing a consolidated technique meant to survey, analyze and replicate existing buildings into semantic BIM models. Moreover, the data interpretation operated by machines could be the most promising scenario for the digital transition in the built environment: when most of the knowledge contents about buildings and monuments will be no longer intelligible only to the human perception, but they will be extended to the machine through a shared digital language, analysis, estimations, and different operational schemes will probably allow the choice of the right intervention through many alternatives, leading to an increased quality for restorations and renovations.

INTRODUCTION: BIM, HISTORIC BIM AND THE CONFUSED DIGITIZATION SCENARIO

The Building Information Modeling is a data management process actually adopted for decades in the AEC domain, especially all over the north American countries. Nevertheless, especially in Europe, its real potential has been focused only in recent years in terms of interoperability and data exchange, features whose interactive language made of digital models has started to be backed by today's computational hardware and software increasing performance.

However, the application of BIM processes and tools to existing buildings is still challenging, since the complexity of the built domain is often way difficult to manage when compared to new construction tasks, due to the frequent lack of data sources on techniques adopted and materials applied, as quoted by Volk, Stengel and Schultman (2013). Also, standard workflows and best practices dedicated to the built environment, in terms of codes, laws and regulations, are almost missing or unshared across different countries; this context leads to wide BIM experimentation currently in progress all over Europe, particularly on monumental sites or consolidated urban areas.

Novel technologies in architectural survey and digital representation, in fact, foster the transition towards the digitalization, even if some misunderstandings in terms and expressions still bring confusion to the actors involved in the process. The term HBIM, for example, is widely and unconsciously used when referring to any kind of intervention on an existing building, where perhaps 3D parametric models are involved as well. HBIM is becoming this way a synonym for "BIM technology applied to the existing buildings". On the contrary, the term comes from the scientific literature, where it is explicitly declared that the "Historic Building Information Modelling (HBIM) is a novel prototype library of parametric objects, based on historic architectural data, in addition to a mapping system for plotting the library objects onto laser scan survey data" as expressed by Maurice Murphy in 2009. HBIM is actually some sort of form-fitting between high definition surveys and man-made digital abstractions made of architectural components: existing buildings, regardless of their function, are easily and quickly detected using accurate tools and consolidated workflows such as TLS (terrestrial laser scanning, as suggested by Grussenmeyer and Hanke, 2010) or digital photogrammetry (whose feasibility was proved by Jean Angelo Beraldin, 2004, among others), so that the point clouds produced are then compared to software libraries made of objects that are placed on the top of the cloud until the resemblance of the model obtained is satisfactory.

It is easy to understand that this process aims at a general abstraction for geometries only, with the purpose to author lean models whose elements are meant to express an intrinsic architectural meaning related to their shapes and relationships (semantics), while the data collection from documentation or numerical sources embedding information into geometries comes only at a later time, to express all the BIM data management potential. HBIM is actually a technique, while BIM is more in general a process whose language is made of digital models, as reported by Eastman, Sacks, Teicholz and Liston (2008). Similarly, the term Scan-to-BIM is frequently misinterpreted, improperly used to identify the mostly handmade process of translation of data survey into 3D models; on the contrary it is important to understand how a BIM model is primarily a database in which the morphology is only one of the available data, even though extremely useful as a friendly user interface to browse easily extended metadata as defined by Mill, Alt and Liias (2013). This way, terms like BIM, HBIM (with its "flavors" Heritage BIM and Historic BIM) or Scan-to-BIM are becoming sort of homogeneous synonyms meant to generally identify interventions on constructions. Many scientific contributions discussing these themes, in fact, can be found on Scopus, ScienceDirect, and Google Scholar as mentioned by Lopez, Lerones, Llamas, Garcia Bermejo and Zalama (2018), who counted a total of 131 papers that were published between 2007 and 2018.

However, in this evolving context, the interest in information modeling techniques applied to the already built architectures is clearly increasing: the advantages in BIM-oriented restorations and renovations lead to a better understanding of constructions, a coherent collection of documents pertaining buildings and facilities, and better estimations on costs and resources.

THE DIGITAL TRANSFORMATION FOR THE BUILT ENVIRONMENT

Notoriously, language is the human faculty to express and communicate, in written or spoken form, articulated concepts through syntax and grammatical rules. The advent of digital frameworks, however, has introduced considerable changes in communications, arousing the fear of traditional idioms to disappear on one hand, while pushing the use of standardized common languages on the other. Technical English, as a typical example, has been elected as a reference for the global sharing of scientific information for software programming comments, favoring the genesis of IT neologisms in different languages.

The digitalization of the built environment is therefore a form of mutable, fluid and synergistic expression, which is articulated on several levels to combine the initial thought to the final result, the digital model to the real built architecture. However, it is necessary to understand correctly at what level of "spoken digitalization" to aspire, at least in its main contexts: as Jason Bloomberg (2018) wrote, digitization, digitalization and digital transformation are terms that express meanings very different in the language of the digital transition.

If the digitization is some kind of translation from traditional sources (paper documents, photographs, negatives and physical models) to computer-readable digital formats composed of bits (an optical scan of a paper sheet is an example), it has not to be confused, as often happens, with the digitalization, which is rather the process that can be implemented at an industrial level through which traditional interactions and exchanges are assisted by digital technologies (in the form of data models), leading to many benefits in terms of optimization and broadcasting. Digitalization is more comparable to a process of change that must be designed and that can start temporarily from digitization, both socially and productively.

On the contrary, the digital transformation is something that individual industries cannot approach by themselves, since it refers to a deep revolution in the business model of the whole AEC system level: it is able to influence the productive chain's behaviors over the long term.

(Figure 2)

These words are paramount in the application of the BIM paradigm to the built environment, since they represent different stages of the development of proper methodologies to face the many issues connected to the maturity level of professionals and scholars involved. If approaches such as HBIM or Scan-to-BIM are proper digitization for architecture, not necessarily monumental or placed in historical contexts, the digitalization is the step where all the data pertaining to the subject, its development, its inner historic essence and the evolutions that occurred over time can be shared among scholars, professionals and practitioners using the common language made of BIM models, which become the expression of a process, where all the BIM positive incomes in terms of reliability, optimization and organization can be extended to existing constructions, considering the digital transformation as a far perspective for the whole AEC industrial chain.

In other words, the digital transformation changes all the ways in which the building process is traditionally conceived by the involved figures, ferrying them from traditional operational practices towards original ones, implemented with advanced tools able to relate to each other through a language made of digital semantic relationships.

From a commercial perspective, the digital transformation will be a key asset initially in the public procurement of many countries, but it will be soon adopted also in the private sector.

Figure 1: The typical authoring workflow to get digital BIM elements out from terrestrial laser scanning. The real architectural component (a), the registered and segmented point cloud (b), the BIM abstraction authored translating the point cloud into semantic objects (c). The geometric element is now able to host linked information related to materials, building technologies, maintenance or technical specifications (Survey campaign, data processing and BIM model of a traditional Italian building by S. Garagnani, 2015).

TOWARDS A BIM PROCESS DEDICATED TO THE EXISTING BUILDINGS

It is somehow justifiable the pathway made of all the reasons that nowadays are pushing survey technologies in the rush to the digital transition; even if dedicated software do not still fully allow a complete automatic workflow in the features extraction and translation of digital surveys into BIM-ready all-inclusive data models, progresses are encouraging, as written by Xiong (2013) or considering the research work by Zhang and Zakhor (2014). The continuous data browsing and information embedding into models generated from digital surveys is paramount never than before, since the documentation authored in a BIM process is made first of all with the final goal of software interoperability and data sharing in mind as quoted by Quattrini, Malinverni, Clini, Nespeca and Orlietti (2015). This is very important in order to foster a digital transition as pointed out accordingly by many European best practices and regulations, which are introducing data fields in the IT language frameworks and proper Levels of Developments (LoD) dedicated to restorations and renovations. While the digitization carried out with increasingly feasible software is preluding to a digitalization made of more or less binding regulations, some standardization of the whole process is necessary.
Even if the LoD concept introduced the amount of information necessary for the different stages of the construction process among operators, when dealing with existing buildings is very hard to comply with predetermined thresholds. On the other hand, it would be difficult to lay standards out without a common level of knowledge embedded into digital models for different purposes. This is the reason why the digital transformation for interventions on existing buildings is a matter of arbitration, since every single case study is different and professional figures called to design renovations or restorations have to be prepared to evaluate the importance of data sources.

Figure 2: The most common authoring workflow to get digital BIM models from UAV digital photogrammetry. The real building (a), the registered point cloud processed from aerial pictures (b), the BIM abstraction authored translating the point cloud into a semantic object taking advantage of a BIM software environment (c), the final digital model meant to index embedded data about preservation of materials, as-built documents, structural simulation results and so forth (d) (Survey campaign, data processing and BIM model of a built sluice close to the Po river by S. Garagnani, 2016).

However, some common ground can be identified in digital modelling for the as-built scenario: while architectural components and their preservation are variable parameters, their semantics can be similar. This way, components' behaviors become a discerning feature in data layouts. Many case studies were approached following this process, leading to a framework that can be applied also to the archaeological field .

Building Information Modeling relies on a paramount feature, which is represented by "smart objects", architectural components self-aware of their identity and conscious of their interactions with each other. Smart objects are hard coded in BIM applications and they contain not only a morphological definition, usually ruled by numerical parameters, but interaction routines as well (e.g., doors and windows belong to walls, floor slabs are perpendicular to walls, trusses distribute their loads on pillars, and so forth). To translate existing buildings into digital models just like the ones used to design new constructions, families of smart objects representing real elements are needed. Again, components have to be acquired and prepared. As a consequence, three kinds of knowledge about them need characterization: knowledge about the object shapes, knowledge about their identities and knowledge about the relationships between elements. While the last two aspects are generally obtained by the investigation of semantics and undergoing analysis and trials, the first one can successfully take advantage of digitization techniques.

The application of this process to the built environment is although very different from traditional 3D modeling: a BIM model is hierarchically structured,

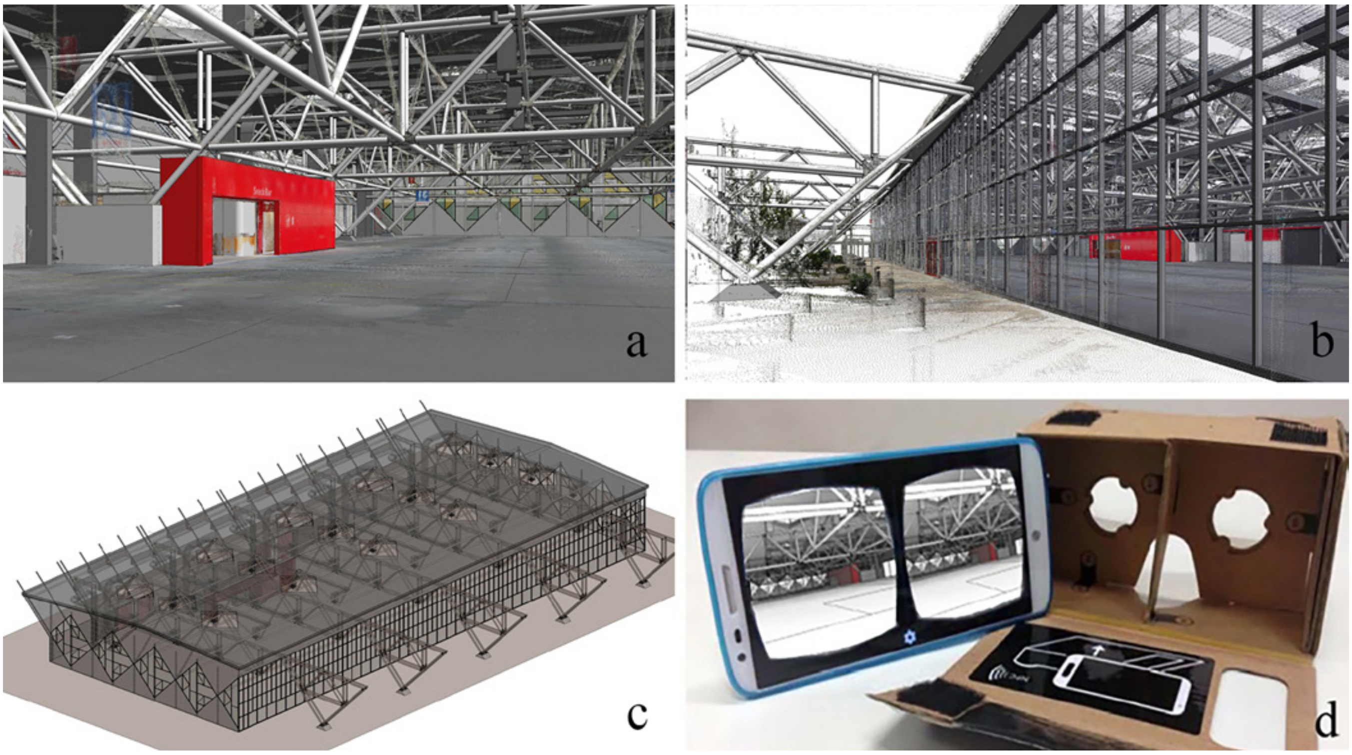

Figure 3: A cheap and feasible technology meant to experience digital models into a Virtual Reality environment. A simple VR app for smartphones is able to replicate into a dynamic stereoscopic view the BIM model (d), made of aggregated semantic components (c), authored from a superimposed TLS point cloud (a, b). The smartphone's sensors detect all the head movements, so the model view is changed accordingly (Survey campaign, data processing, app development and BIM model of Bologna Fiere's Pavillion no. 31 by S. Garagnani, 2017).

it can be used to filter information for various stakeholders (maybe interested in restoration or preservation), thence it can be made of parametric "smart" components, slightly lighter in computer's memory and much more editable than point clouds or polygonal models got from the surveys.
Following a methodology aimed to translate digitized data sets into segmented elements , many experiences carried out on some case studies during last years on historic buildings can be proposed as a reference in order to express a proper digitalization for the existing domain. The applied and severely tested pipeline basically consists of four stages during which architectural monuments are surveyed with high definition techniques, then properly segmented and finally replicated in their complexities using some software specifically developed.
The first stage of the process is the survey, in which architecture is captured in its morphology, where materials, colors and shapes are documented using digital techniques that often produce point clouds. Modern BIM applications are not designed for this task and, generally, they can import unreferenced pre-processed points as explicit "snaps". Edge detection on registered point clouds has to be often applied to identify components' boundaries and separate them from the heterogeneous, unsorted data set.
During this stage, points belonging to different elements can be simplified following an almost manual semantic attitude, even if topologies, relationships with other components, materials and assembling techniques inferred by human operators cannot be directly transferred in BIM modelers.
In the third stage of the process, registered and divided objects can be studied along with their relationships, their features and materials as these aspects represent important peculiarities of components. In a consolidated approach, segmented point clouds can be used as sort of geometric scaffolding useful to trace regular parametric elements on the point cloud: this process is mostly done by hand, then heavily subjective, time-wasting and almost inaccurate. To bypass these criticalities, the final stage of the process involved three tasks: the geometry modeling of the components in BIM software, the assignment to shapes of their category and material properties and the declaration of relationships between components, as requested by BIM semantics.

Latest developments of software applications by commercial houses will probably make this approach easier to be applied in the near future, however, the BIM process (long before the BIM software) already represents a paradigm shift for the architectural documentation and investigation.

CONCLUSION

If the digital transformation has a powerful development driver in the BIM process, the common language that would allow data sharing becomes extremely important dealing with the built scenario: it is also remarkable the idea, already expressed by Marvin Minsky in 2007, that information collected on the as-built constructions could be processed by machines themselves, following self-learning principles able to aggregate and analyze data according to precise mathematical rules. Simulations of possible scenarios starting from initial variables are just some of the uses that are fueling expectations and fears towards the most recent expressions of artificial intelligence. Terms like Virtual Reality (VR) or Augmented Reality (AR) are already part of many software houses commercial offers, to highlight the importance of real time digital simulations that are a direct consequence of space planning and architectural intents, as widely discussed by Park, Lee, Kwon, and Wang (2013).

But the most promising scenario for the digital transition in the built environment is perhaps the data interpretation as a prerogative meant to be a human exclusive no more: when most of the knowledge contents about buildings and monuments will be no longer intelligible only to the human perception, but they will be extended to the machine through a shared digital language, analysis, estimations, different intents and different operational schemes will probably allow the choice of the right intervention through many alternatives, leading to an increased quality for restorations and renovations.

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13

A BIM-Based IoT Approach to the Construction Site Management

KEYWORDS: BIM-based technologies, IoT, construction site management, sensorization, actuators

BIM-based technologies can be strongly beneficial for construction sites management through platforms collecting data and providing analytics. These can be used to manage and control the people, materials and vehicles flows which create the complex organization of a medium and big construction site. IoT enables monitoring, controlling and actuating devices that are crucial to manage the site. Different typologies of sensors are available and some experimentations about how to simulate and thus predict critical issues in the construction site have been conducted. The experimentations, that are not presuming to be exhaustive, consider both indoor conditions and external situations verifiable through standard procedures. In the paper, four tests, developed in the virtual environment. The adopted workflow assumes the connection of the BIM (Building Information Modeling) authoring tool through a VPL (Visual Programming Language) to a database where data coming from the sensors are stored. The simulations shows the possible actuation of specific devices to correct possible critical situations that are commonly recurrent in construction sites and in the advanced one are implemented. The virtual experimental setups are show how to accomplish the work steps organization and how to visualize alerts and signals enabling the optimization and control of the construction site in a BIM environment. The advantages of this approach are strongly connected to risk and clash reduction in the construction site, increased safety for the workmen and environmental quality. Moreover, the possibility to control the warehouse conditions is highly beneficial to reduce the number of deteriorated materials with economic gains.

INTRODUCTION

The BIM (Building Information Modeling) methodology is radically and irrevocably changing the Construction sector, since it allows a coherent and holistic vision of the project throughout its supply chain. In this sense, there is an increasing awareness of how the information component is the real red thread that connects the phases of the life cycle of an asset from the starting phase of programmatic definition to the disposal. The emergence of this awareness is the Disruptive Force of Digital Transition for the AEC industry.

At this very important moment in history for IoT (Internet of Things), data is essential to support decision-making. In this sense, the partial automation of processes is a key feature of the concept of Industry 4.0. The use of BIM in construction processes provides stakeholders with the opportunity to understand and support decisions through a computational approach. The most recent legal provisions also impose a new way of operating in the building sector: for example, European Directive 2014/24 suggests an assessment of public works no longer limited to the design and construction phase, but extended to the entire useful life, favouring the adoption of information modelling, since it offers the possibility of controlling the overall progress of the project. After transposing European legislation, the Italian legislator went further with Ministerial Decree 560/2017, which established the transition to a BIM approach in public procurement, through a gradual soft-landing process of transition to digital, starting with the most important and strategic works with the objective, by 2025, to extend it to all the contracts. In order to start with this process, it is necessary to enable the direct contact of the client with the BIM methodology.

This crucial operational change is also impacting the construction companies, called upon to change their structure and produce useful data for the building management. However, in order to achieve a real change of approach, the available data should be used for tangible processes innovation and performance control, which means a not typical method for the AEC sector companies. In fact, they usually carry out only the final assessments. This paper aims at highlighting the benefits that the construction site can gain from the adoption of the BIM methodology and the BIM-based technologies, getting the definition and mainly the management of smart site. In particular, the following sections will emphasize the benefits of integrating detection technologies (i.e. sensors) in order to implement the digitization of the site and related processes. In the following paragraphs some simulation experiences conducted during the educational programme of the course Construction Site Organization at the University of Brescia are described and some critical aspects are also unveiled and suggested.

Digital transition: from projects to increasingly correct construction sites

In recent years, buildings and construction sites in general reveal a common denominator: being more and more complex. It is difficult to have for each of them an overall view of the processes, their relationships and the particular spatial-temporal context in which they take place. This complexity also increases the probability and propagation of errors during the whole process from design to construction phases. Although many studies investigated the causes of errors, less is known about the real costs associated with them, it is difficult to establish how to estimate and measure these costs and their effects over the life cycle of the work. Bijen (2003) states that errors in the construction sector account for up to 10% of the total investment for the construction of a work. Lopez (2012) claims that errors in tender documents alone can affect up to 5% of the contract value. According to the Building Research Establishment, in the United Kingdom, at least 50% of errors in the construction and life of the asset are attributable to design. By using BIM, on the other hand, it is possible to considerably reduce these errors, thanks to the continuous control of interdisciplinary design interferences, ensuring a consistent result. Traditionally, designers often work nearly independently of each other, making decisions without considering their impact on the other disciplines.

Contractors often receive incomplete or incorrect documentation, especially when there are tight deadlines to accomplish. Also the contractual forms and the methods of awarding the works have a significant influence on the level of coordination, communication and flow of information between designers. Love (1998) notes that the separation in use between design and construction has led to an ongoing lack of collaboration between those who deal with the work at different times. In contrast to this trend, BIM supports a full and uninterrupted collaboration between all the involved figures (i.e. clients, designers, and, if desired, contractors and others still called upon to give their contribution). BIM requires a unique strategy (Love et al., 2010), which revolves around shared information content, from the beginning to the end of the collaboration. The digital transition pushed by regulations and organized as described above, leads to a combination of digital project and reality. This merge is constantly increasing, thanks to the development of technologies to support the BIM methodology in this regard. Many researches are in fact evolving applications to convey the project to the several stakeholders. This means as first of all, among the designers, for example in the form of visualizations designed to facilitate the communication between themselves and other actors involved in the work, helping the share of design questions and/or executive details to be discussed and approved.

In any case, even during the execution phase, the project developed by means of information modelling permits, on the one hand, greater control of the works and, on the other hand, it facilitates the supervision of the site by the works management office (WMO), the operational managers, the site inspectors and the works manager. In this way, it is possible to achieve a free of errors construction design, or almost. The validation of these models, however, is very complex, especially if no solid rules of modelling are shared. Otherwise, every design structure, as often happens, produces models that are not able to provide added value for the client, but only two- or three-dimensional representations. Although the methodology favours a greater congruence between the documents, the projects drawn up may contain errors and, therefore, must be subject to three different phases of control: (i) validation of the BIM model, (ii) analysis of interference by clash detection and (iii) control of compliance by code checking. Once the project has been validated through these three phases, it can be placed on a competitive basis. The represented design is used by the selected company to carry out an evaluation of the construction methods that is most suited to the realisation of the work. They are responsible for checking the materials used on-site to ensure that they meet the design requirements and for carrying out the work correctly. The different design verifications are only possible if the use of information modeling is accompanied by a systematization of the data, which is, correlating the parameters of the project with the intended use of the methodology. This means that, as PAS 1192-2:2013 argues, in structuring a process, it is in fact necessary to "start with the end in mind": this statement indicates that, during the first phase of the project, the objectives of the project and, consequently, the contents of the specific information modeling must be defined. In this sense, the use of this methodology on site is only possible if it has been established in the preparation of the process that the information modeling should also be used in the construction phase. Therefore, the evolution of the worksite towards the smart, or beyond, towards the cognitive worksite requires a robust methodological basis, a greater attention to the management and formalisation of information by all the actors involved in the process.

MANAGEMENT OF THE SMART AND COGNITIVE CONSTRUCTION SITE

If the project operators are now aware of the urgency of the digital transition, i.e. of the adoption of the BIM, the construction managers are also experimenting its advantages in various ways. In particular, more and more scientific experiments are dedicated to the management of materials, time, equipment and employees. The adoption of a BIM model shared with all the actors of the work, on the one hand encourages the exchange of information, creating an uninterrupted flow between the world of design and that of companies, construction and / or management, without excluding the customer, on the other hand creates the conditions for obtaining a lean process (Lean) (Womack et al., 2003). In order to transfer this production model from the manufacturing sector to the construction sector, which has remained at a standstill for too many years, it is needed to act on the information side of the BIM methodology, an aspect that is often left in the background compared to the graphic one.
Being able to manage a large amount of data allows us to develop increasingly complex reasoning on the product, which often go beyond the individual disciplines involved and find a synthesis in the best allocation of processing time and overall costs, which means the sum of those necessary for supplies, equipment and employees. Through this approach, (i) an optimal planning of the activities, inside and outside the site, as a result of the analysis of alternative procedures, is now possible mostly as a preventive measure; (ii) a reduction in waste, both in terms of processing time and costs, including those for safety; (iv) a continuous monitoring of the current situation, which, if necessary, can be gradually corrected to respect time and costs. These issues are becoming increasingly complex as the size of the project grows, requiring a systematic approach to information on-site. The smart site is a connected site through devices and actuators that can optimize, speed up and increase the productivity and safety of the procedures. The

cognitive site goes beyond and applying machine learning algorithms could learn by the data and predict issues and propose solutions increasing to a higher level the autonomization of the procedures.

Platform and technologies

The management of the cognitive site is a complex operation that must be regulated in order to keep under control all the processes that take place in situ. In order to control the entire process, a platform must be used (Benammar, 2018) that allows different stakeholders to access it with different levels of permits.

The use of a stand-alone management system would involve the implementation of only one aspect of the site, creating redundancy of incompatible and not interconnected systems. For this reason, the use of a single, possibly web-based platform would ensure that the actors in the process use a common basis for data exchange. In this way, the instruments used to manage the various aspects of the site (such as safety, material management, interference, etc.) would be optimized and perform multiple functions. It is in this direction that many companies are moving to set up platforms (such as BIM 360 layout, STR Vision Team Work, Evolvea, Tekla BIM Sight) able to manage and verify the compliance with the requirements on safety and coordination of workmen by monitoring in real time, with wireless sensors, the onset of risk factors and compliance with prescriptions. These multi-level architectures are able to record and analyse data in order to obtain statistics on site behaviour and, finally, provide monitoring and final reports. This structure acquires data from the field infrastructure, which connects and locates sensors, tags and badges, developing data management and storage in the Cloud. In this way, the surveys are analysed in real time, identifying and proactively reporting risk situations (Toole, 2002, Zou, 2009) and non-compliance with prevention and protection procedures.

Users can only access data using credentials connected to a user profile such that certain information is made available depending on the level of the person and the affiliation. The interface allows to manage three-dimensional monitoring with all the information required for the geographical location and progress of the activities. In this way, it is possible to simultaneously control multiple sites located in areas that are also very distant from each other, optimising the use of staffs responsible for managing warnings and anomalies in the construction sites. These structures are able to locate in real time, both indoors and outdoors, people, equipment, means of work, as well as materials with presence control and access authorisations to the various construction site areas. This approach can identify and monitor operational interference that exists between workmen in the same area or by means of vehicles, indicating hazards with respect to moving vehicles. On a cognitive site, the aspects listed above are just some of the possible uses in terms of safety and resource management, which are made possible by the introduction of sensors and actuators. The extensibility and scalability of these systems allow the customization of the system contents according to the needs of the construction site the idea of cognitive includes machine learning algorithms to introduce a responsiveness related to behaviours. In a smart construction site to close the control loop information are delivered back to machines or people in the form of locations of other objects or instructions for movement, in a cognitive concept the machines and materials can implement their intelligence through data analytics and machine learning to introduce predictive logics.

In particular, it’s worthy to underline as that certain controls such as, for example, the humidity level in a work area are not necessary, or superfluous, on a civil construction site, but in the case of a tunnel construction it is a very important factor. The purpose of this document is to explain the possible uses and integrations of this system. In particular, we can identify sensors for (i) tracing people or property, (ii) environmental detection (e.g. air quality, noise levels, etc.), (iii) access to areas and (iv) environmental adaptation. The use of sensors on site is made possible by an interconnection network that can detect the presence of new devices and insert them into the monitoring system. In the same way, the removal and movement of network devices is also extremely easy and therefore suitable for temporary installations. The positioned devices connect autonomously to the others to configure a radio coverage of the chosen zone. All data is conveyed to and from one or more gateways, connecting the network to the Internet and then to the servers and clients of the platform (Valero, 2016). However, it should be pointed out that the use of tools to trace people oversteps the personal privacy of workmen, which is why these tools entrust each workman with a user with certain characteristics that he or she possesses (such as qualifications, IPR, patents, etc.), but does not allow system administrators to view the identity of the person. Only in situations of danger (i.e. in the presence of accidents) is the administrator allowed to link the workman's identification with his/her real identity.

METHODOLOGY

The adopted methodology pursues to connect data coming from IoT devices such as sensors that could be used to locate materials, people and machines. The method adopted uses VPL to realize a workflow of interconnection between data collected and the BIM model which is the virtual environment of control of the construction site (digital twin). Inside the virtual environment controls are structured by colour codes and actuations could be implemented towards the communication architecture pervading the construction site. The main methodological workflow is depicted in Figure 1: sensors data are simulated and written in a database such as an excel file, and then translated to the BIM model by a dynamo script and actuation or a control system about environmental conditions, workmen' safety and machineries location is implemented.

CASE STUDIES

The field of application of IoT to BIM is wide and in this paper a short introduction has been given in the previous sections. The objective of the paper is to describe some case studies about how to use the data gathered in the construction site through a BIM model to control, enable and implement advanced features for the construction site. Four case studies are described in the following sections:

1. Control of environmental conditions in the areas of a construction site;
2. Dust control in the different areas in the construction site;
3. Man down safety control in the areas of a construction site
4. Localization of machines in the areas of a construction site.

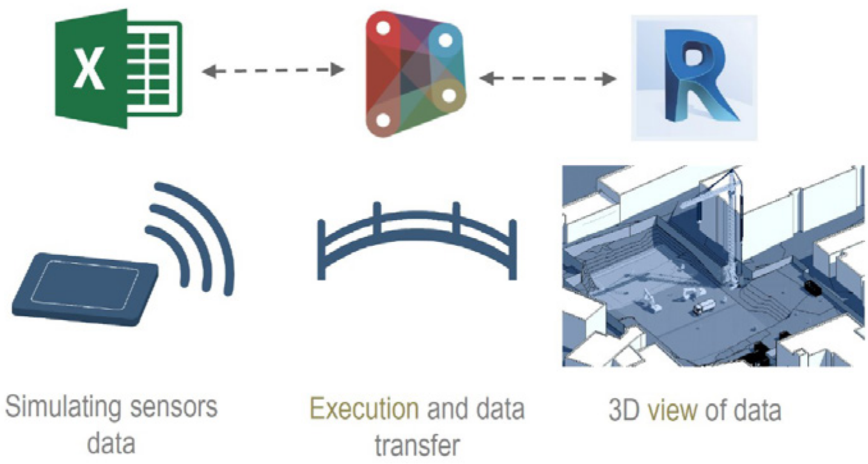


Figure 1: Workflow between the data collected by sensors in the construction site and the BIM model in Autodesk Revit where 3D data are shown to perform controls and actuations.

RESULTS AND DISCUSSION

In the following sections the four case studies about IoT and BIM connection for construction site are described and possible applications highlighted.

Control of environmental conditions in the areas of a construction site

The first case study has been performed to simulate the indoor condition for the construction site considering specific thresholds for the adopted parameters. The possible applications of this approach are wide considering the data that can be gathered by sensors installed and the environmental control parameters such as: temperature; relative humidity; smog/pollution; dust particulate; pressure; smoke; noise; VOC levels. The same concept could be implemented to monitor and decrease fire outbreaks, water leaks and claims. In the present case, the indoor air temperature and relative humidity have been used as main control parameters and values have been identified to simulate the data collection by sensors and the verification of the indoor conditions. The thresholds are defined in compliance with standard safety and comfort values (UNI EN ISO 7730) such as: 18°C < air temperature (T) < 22°C; 65% < relative humidity (H) < 75%. The reported ranges state the correct conditions and thus the colour code "green" is displayed, while the values are lower or higher than the thresholds the values are reported as not compliant and consequently combined with a "red" colour code. The data have been collected and organized in an excel file as repository as shown in Table 1.

In Figure 2 the result of the simulation is presented. It is thus possible to envisage in the BIM model the critical areas and promote a tailored service to relocate resources which could have problems with indoor and storage conditions or increase the comfort for the workmen in the construction site areas.

Sensor code	*Floor*	*Air temperature*	*Relative humidity*
P0.02	*Ground*	*17.73*	*71.17*
P2.05	*Second*	*17.79*	*74.04*
P1.13	*First*	*21.39*	*77.28*
P2.20	*Second*	*21.04*	*69.28*
P0.07	*Ground*	*21.05*	*75.27*
P0.06	*Ground*	*20.61*	*75.23*
P1.14	*First*	*17.75*	*67.24*
P2.18	*Second*	*20.57*	*74.11*
P2.23	*Second*	*20.36*	*68.56*
P2.09	*Second*	*20.87*	*76.03*
P2.11	*Second*	*18.32*	*77.15*
P2.15	*Second*	*22.71*	*73.73*
P-1.03	*Underground*	*20.08*	*89.33*
P0.03	*Ground*	*19.60*	*75.92*
P2.14	*Second*	*20.74*	*75.40*
P-1.04	*Underground*	*32.54*	*74.16*

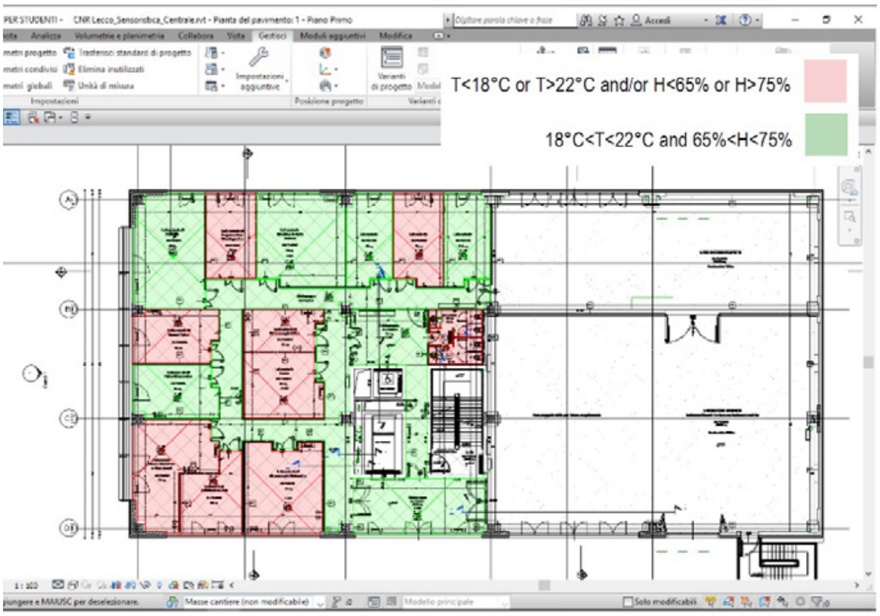


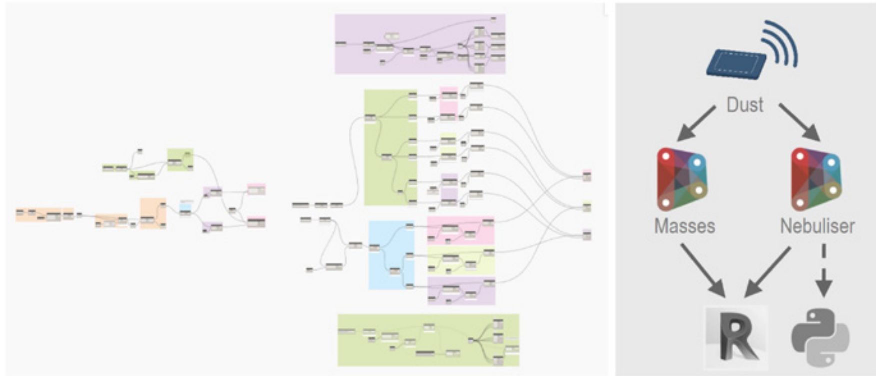
Table 1: Example of data of air temperature and relative humidity collected by field sensors in the construction site.
Figure 2: Colour code to underline the levels of temperature and relative humidity.

Dust control in the different areas of the construction site

The second simulation is about the measurement and control of dust in the construction site related to different areas. In this simulation the BIM model of the construction site has been realized with different section corresponding to masses and the sensors referred to the values of the excel repository. The main task is to monitor the environmental condition but a step forward is to endorse the actuation of a nebulizer to reduce the presence of dust. A dynamo script has been executed to read the excel data virtually coming from the sensors and write the parameters in the BIM model in the Autodesk Revit authoring software (Figure 3). A colour code has been applied to the construction site areas to define thresholds to activate the nebulizer (Figure 4). In Table 2 the organisation of the BIM model in the simulation is shown including the values of dust.

The simulation allows to understand how to define the conditions of different areas in the construction site however it is critical to define the different areas and the relevance of the various processes and location. The masses that define the area in which the dust control is empowered have been defined in correlation to the excavation areas however the areas could change during the progress of the work. It is worthy to note how the information model should be correlated with the organisation of the construction phases of the site to avoid methodological discrepancies or inconsistencies.

Number	*Name*	*Dust level*
1	*Mass 1*	*55*
2	*Mass 2*	*75*
3	*Excavation area*	*5*



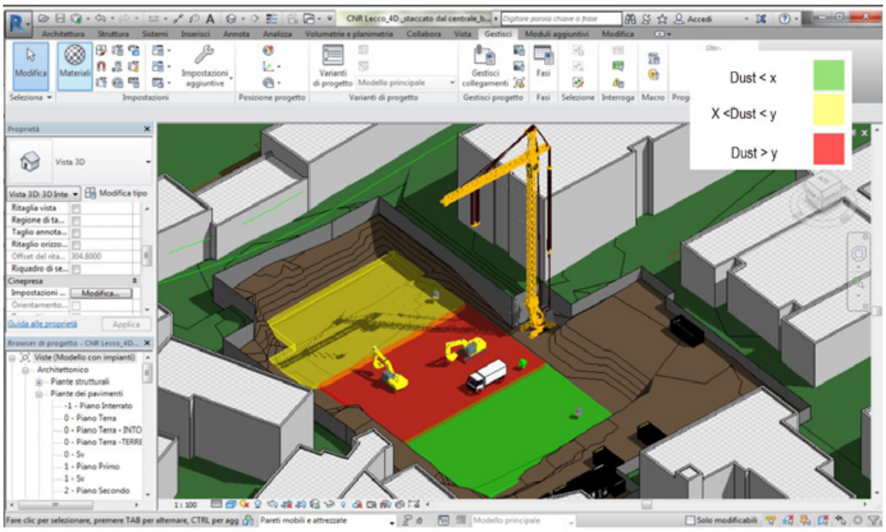


Table 2: Example of data of dust collected by field sensors in the different areas in the construction site.
Figure 3: Dynamo script and workflow from sensor to model to monitor and control the dust.
Figure 4: Simulation of control of dust through BIM model masses and IoT approach.

Man down safety control in the areas of a construction site

The man down and PPE (Personal Protection Equipment) are crucial for safety procedures in the construction site. The application of the IoT to BIM connection are referred to security and safety applications and access control to restricted access areas. The two sensors related to the worn PPE and man down signal converge to the dynamo script who transfers to the BIM model the information related to the colour code.

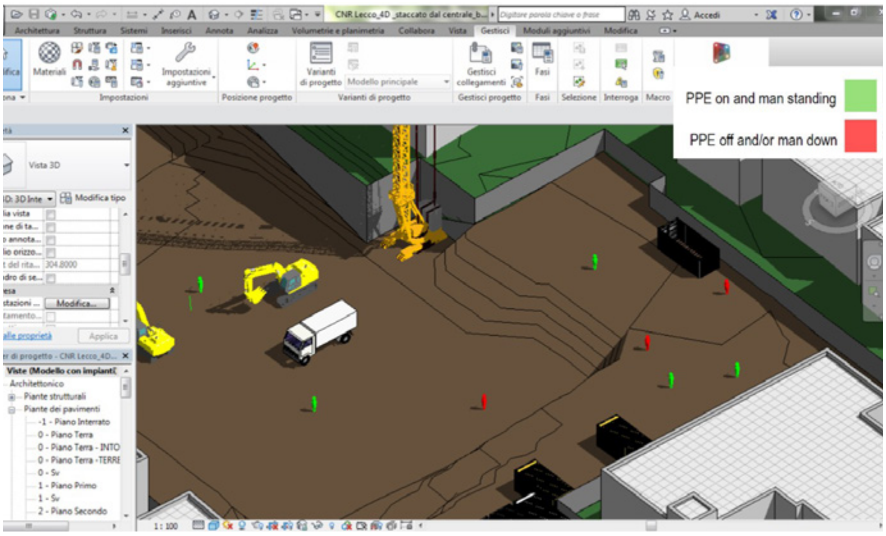
The colour code is assigned for the PPE on (worn) and man standing as “green” light or correct procedure and “red” light and alert signal for the PPE off and/or the man down signal as shown in Figure 5. The association of the two information could bring to a same emergency level however it could be differ for safety procedure.

Localization of machines in the areas of a construction site

The localization of the machines in the areas of the construction site is a very important issue and accidents and safety problems could be avoided and controlled by using sensors to delimit the areas (i.e. cones sensors as RFID Radio-Frequency IDentification) that are connected to the sensor in the machine (i.e. GPS Global Positioning System) used to identify its location. The aim of the experimentation is to know the number of machines in a specific area aiming at optimize the flows and the resources. The IoT to BIM workflow could be applicable to define density of machines in a specific area and density of workmen in the areas.

The process could be supported both outdoor and indoor. The actual coordinates of the machines are converted with a dynamo script in the BIM environment and then compared to the masses used to define the areas in the construction site. In this way it is possible to determine if a specific machine is in a defined area and verify

Number	*Name*	*PPE*	*Man down*	*Presence*
1	*Workman 1*	*Yes*	*No*	*No*
2	*Workman 2*	*Yes*	*No*	*Yes*
3	*Workman 3*	*Yes*	*No*	*Yes*
4	*Shipyard*	*Yes*	*No*	*Yes*
5	*Driver*	*Yes*	*No*	*Yes*
6	*Electrician 1*	*No*	*Yes*	*Yes*
7	*Installer 1*	*No*	*No*	*yes*
8	*Crane driver 1*	*Yes*	*No*	*Yes*
9	*Workman 4*	*Yes*	*No*	*Yes*
10	*Workman 5*	*No*	*No*	*Yes*



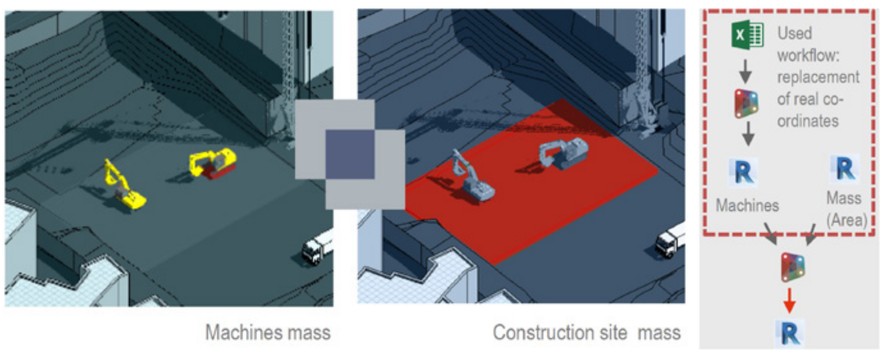


Table 3: Example of data for the man down and presence control of people.
Figure 5: Simulation of man down and PPE control in the construction site.
Figure 6: Masses for machines and mass for the areas in the construction site and workflow.

if there are incompatibilities and issues to solve.
The simulation could be used to enable processes of recognition of position for elements in the construction site such as pillars, beams, etc. adopting a control procedure and a colour code to highlight possible errors in the positioning of such elements. In this case it is also crucial to define the different areas of the construction site in a congruent and relevant manner to unveil issues. The concept of "start with the end in mind" continues to be core point for a BIM-enabled IoT optimization approach.

Figure 7: Simulation of machines localization in specific areas in the construction site.

CONCLUSION

The cognitive construction site, enabled by IoT technologies and BIM methodology, allows to increase productivity and decrease time and costs. A lot of factors can increase of +80% the cost of a construction, for change in work plan, not available working areas, underestimated efforts, weather conditions, previous handoff incomplete, not available materials and labour. Most of these factors can be corrected by an IoT approach by sensing the procedures and materials, tracking machines and workmen to optimize flows and increase safety and compliance of optimized procedures. The paper shows some case studies where a workflow to connect data gathered by sensors that could be installed in the construction site enable to implement the control procedures: improving environment conditions, controlling and actuating actions to correct uncompliant conditions, increase safety and enabling emergency procedures, locate in the correct place of the construction site machines, workmen and elements that could be beneficial to be monitored in the work progress. The proposed workflow supports the project management and the use of data for statistical analysis providing a graphic visualization of the information in the same platform however the interconnection between different software is needed and automatization could be implemented through an interpreted, object-oriented, high-level programming language with dynamic semantics.

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14

Knowledge Methods to Extend the Service Life of Historic Timber Roofs

KEYWORDS: CONSTRUCTION HISTORY AND PRESERVATION; TERRESTRIAL LASER SCANNING; PARAMETRIC MODELING AND RECONSTRUCTION; TIMBER HYGROSCOPIC AND RHEOLOGICAL BEHAVIOR; SERVICE LIFE

The analysis of historical timber roofs is a topic widely dealt with in literature both in the disciplinary field of "theory of construction" and "construction technologies", and in that of architectural technology and restoration. The specialist literature, however, has often simplified the constructive conception and evolution of these artifacts that, even when they stand still to date, show the signs of a long life, often hidden and little-known, even with regard to frequent changes over time. This paper aims to outline a methodological approach for an in-depth assessment of historic timber roofs, in order to extend their service life. In a holistic conception, digital technologies collaborate to identify mechanical, rheological and hygroscopic phenomena on wood elements over time, highlighting displacements, deformations and, generally, decay. Some case studies analyzed in the territory of Bologna were a useful starting point to achieve a thorough understanding of these artifacts, primarily based on survey, digital modeling and structural analysis. This academic approach, based on generative algorithms, is useful to attempt a more in-depth and transversal understanding of the behavior of these wooden structures, focusing on geometric surveying and constructive analysis. Developing and following a methodology accelerates modeling procedures and brings on new tools for analyzing these structural systems surveyed through Terrestrial Laser Scanning (TLS) devices. It also enables to store acquired results in BIM models in order to perform further analyses over time. The acquired knowledge of the structural behavior of timber structures is fundamental for their maintenance and for potential renovation.

INTRODUCTION

The analysis of historic roofing structures, in particular timber trusses, is present in many scientific contributions in the fields of building science and construction technology. Nevertheless, only a few studies have deeply investigated the behavior of these construction systems in a life cycle perspective, on the basis of detailed survey. This is justified by various factors, including that roofing structures are usually hidden and don't attract the attention of architects and engineers, except in case of severe damage, with imminent consequences on people's safety. However, the roof is a part of the building that is particularly subject to deterioration and fire, being characterized by strong modifications and partial replacements over time. To a certain extent, the service life of a roof determines the service life of the entire building.

One of the main reasons for the lack of attention lies in the fact that wooden roofs are typically indeterminate structures, whose safety depends mostly on the reliability of the original scheme, on the quality of wood and on the condition of knots and joints. In other words, it pertains to the art of building, to the practice of carpentry and for this reason it eludes scientific and analytical interpretations, if not at the cost of large approximations. Understanding the geometry, the structural behavior and the decay of wood is the key factor to extend the service life of a timber structure: partial replacements of parts can be part of the maintenance strategy.

The method proposed here for the assessment of timber trusses is compatible with the standard procedures and it is based on an accurate geometric survey of the structural parts of the roof. Following the survey, it is possible to go back to the original geometry of the structure through the rational use of reverse engineering software. Furthermore, counting on the development of detailed geometric models, it is possible to perform precise analyses on the rheological and hygroscopic behavior of the structures during their life cycle. All the information can be stored and confronted in a BIM model.

Figure 1: The roof of San Petronio, Bologna.

THE KNOWLEDGE OF HISTORIC TIMBER ROOFS AND TRUSSES

In construction history timber trusses are the main structures of timber roofs. They are commonly used to cover big halls and, particularly, the naves of the churches. These types of structures are conceived both as planar and tri-dimensional systems and realized with girders of solid wood of different sections, depending on the roof span. The ability to redistribute the vertical load without producing horizontal thrust on lateral walls gave success to these structural configurations since the beginning of the IV century.

Before the use of scientific methods, the architects used to solve the problem of building durable roofing systems following the advice of master builders and carpenters for their ability to produce and assemble reliable structural elements. Example of noteworthy trusses are represented by many architects in famous manuals, starting from the XV century (Philibert Delorme, Leonardo da Vinci, Taccola, G.B da Sangallo), but construction mostly depended on practice. In a well-known table by Sebastiano Serlio, titled armamenti di legname, the architect states that «the timber master will know how to manage it according to the place, therefore he won 't give any measures other than those in the drawings». These words clearly leave the selection of the beam sections and the solution of the details to the carpenters. The same statement can be applied to the maintenance of the roofs over time: the elements were continuously monitored and eventually replaced with new members, according to the evaluation of timber experts, not necessarily architects.

It is difficult to say how much roof construction in Europe derived from local culture, and how much the carpenters were travelling, spreading their knowledge in different regions. The construction and maintenance of trusses have certainly followed the culture of place, strongly depending on functional needs and materials supply. In Central Italy only, some species of wood were available, usually hardwood (chestnut, walnut, poplar, oak, pine). If the carpenters needed soft wood (fir) to build slender elements, they didn't hesitate to import the material from the Alpine region. We had evidence of that form historic documents in Bologna.

Southern European trusses are usually heavy structures, made with hard wood, while Northern European structures tend to be light structures. Heavy timber trusses are quite simple in form, and composed by a few elements. There are two basic systems: the system with a king post between the rafters, with or without braces (capriata semplice o all'italiana) and the system with a collar beam and queen posts (capriata palladiana). The scheme was the same for most of the trusses, up to a span of 15 meters. Beyond that dimension, it is usual to observe additional elements. (Fig.01)

A key issue in trusses construction is the function of the king post and its relation to the tie-beam. Some authors call "false truss" or truss-beam (falsa capriata, capriata trave) a truss where the king post rests on the tie-beam (pseudo-catena) and the rafters (falsi puntoni) on the king post. A similar distinction is made between open joint trusses and closed joint trusses. In open joint trusses (capriata a nodo aperto) the joint between the king post and the tie-beam is made through a not nailed steel bracket with the aim of simply maintaining the planarity of the structure, and avoiding the loads transfer; in the closed joint truss (capriata a nodo chiuso) the king post is placed on top of the tie-beam or clearly jointed (hinged), generating some bending moment in the element. (Fig.02)

The illustrations of the Traité theorique et pratique de l'Art de Batir by Rondelet (Planches from CIII to CXII) try to give an interpretation of the text of Vitruvius and show truss-beams and closed joint trusses. In Central Italy (Tuscany, Lazio, with the cities of Florence and Rome) the king post is frequently detached from the tie-beam, while in Northern Italy (Veneto, Lombardia with the cities of Milan and Venice), and in other parts Europe, as well as in most Architectural Treaties, it is linked to the tie-beam. In fact, Palladio, who was actively working in the Veneto region, describes and draws closed joint trusses:

Figure 2: Detail of bracket and wedges of a tie-beam in San Pietro, Bologna.

> There are various manners of disposing the timber of the roofs; but when the middle walls support the beams, they are very easily accomodated; which method pleaseth me very much, because the outwalls do not bear: so much weight, and altho' the head of some beam should rot, the roof is not withstanding in no danger

Similarly, in his drawings Philibert Delorme identifies closed joints (bolted joints). Until the XVI century the Italian experience was very influential in the work of European architects. In their structural conception Northern European trusses tend to become lighter and more complex over time.

While the knowledge of wide span wooden roofing, in particular timber trusses, is based on the analysis of old textbooks, the interpretation of the mechanical behavior usually follows the XIX century approach, simplifying complex and partly structurally indeterminate systems into manageable and computable truss diagrams. The technical solutions identified for strengthening or preservation are often based on those simplifying assumptions.

Our assumption is that digital technologies for surveying enable a series of new and original considerations that would be almost unworkable following the traditional methods based on direct observations and simplified architectural surveys.

While the use of the laser scanner in the survey of old buildings is quite widespread, less frequent, if not absent, is the application of this technology to hidden spatial structures as timber roofs. Studies in this direction, at least in Italy, are very few. The starting hypothesis is to take advantage of the large amount of geometric data acquired in form of point clouds, in order to analyze the trusses in detail and derive accurate information on their behavior. The acquisition of further information allows to trace the logic of construction and, above all, the process of assembly of the structures from the very beginning. In fact, the geometry of the trusses follows a very precise, and often ignored, construction process linked to the possibility of raising the elements up to the base of the roof, refining and assembling them through other supporting elements and, finally, joining them using metal nails. Nowadays, the system for joining wooden elements is completely changed with the introduction of metal plates and the possibility to check every part of the system numerically; as a matter of fact, retracing the original logic of the junctions is a non-trivial task. Besides, extensive and detailed geometric information provide highly interesting data on deformations and displacements. These modifications in shape occur both at local level, i.e. in a single element, and at global level, considering the behavior of the whole roofing system. Traditionally, roof systems have been studied in two dimensions. The global behavior, provided by movements and reciprocal interferences in the longitudinal direction, has often been ignored in favor of the behavior of the single truss in its virtual plane.

A further consideration concerns the intervention on this type of structures: a poor understanding of the original construction leads to interventions that bring back the behavior of trusses to simplified schemes, introducing stiffeners and other superfluous structures that are radically changing the original behavior of the structure. Recent major refurbishment interventions in Bologna, as we have observed, have shown a deep misunderstanding of the structural behavior, both locally and globally. Not to mention the adoption of extended replacements of elements that have created problems not only to the roof system, but also to the whole building.

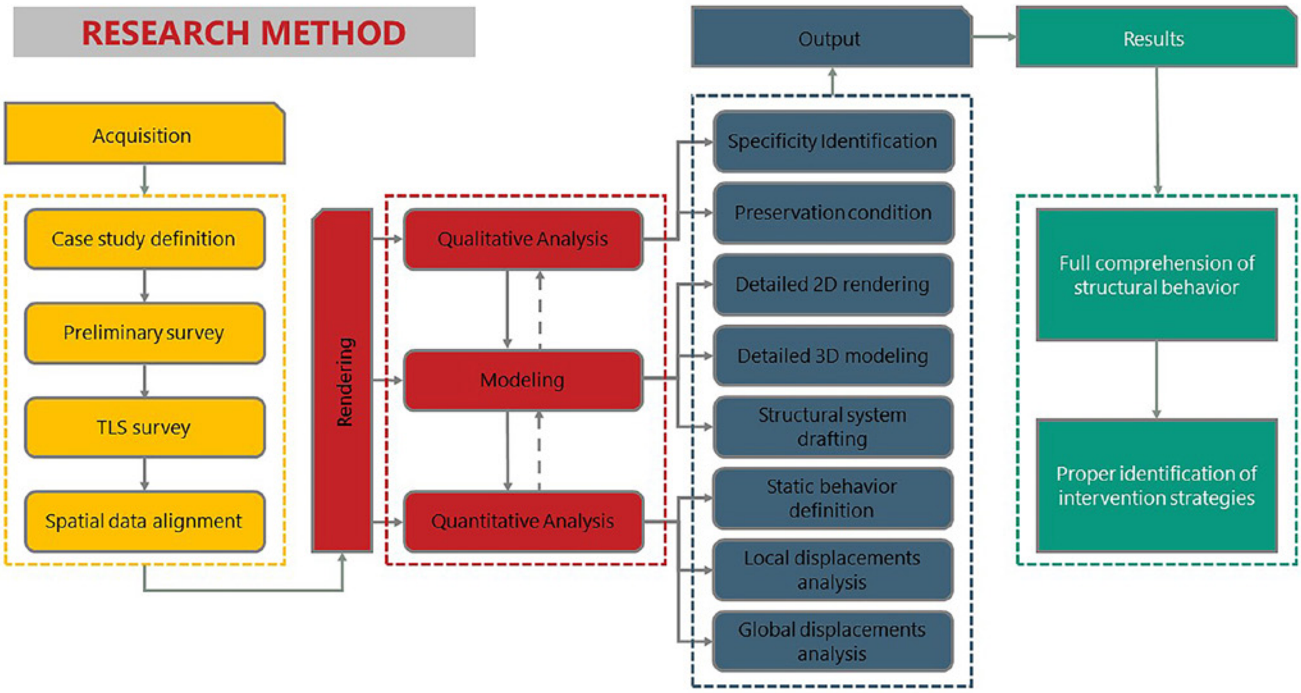
LIFE CYCLE OF HISTORIC TIMBER ROOFS

The life cycle of a timber structure can be very long; in many churches of Bologna the same structures have been used for more than 400 hundred years. In some case many parts of the trusses were replaced; in other occasions the elements were disassembled and then re-assembled. If they were found excessively deformed or damaged by humidity or animals, they were cut, shortened, turned upside down and eventually replaced.

The maintenance of any historic roof of particular importance (palazzos, churches, theatres) has always been essential over the years to ensure a very long lifecycle: interventions were continuous and represented one of the main running costs of the building, before the services were introduced and the energy consumption became a major issue. The good functioning of the building mainly depended on the good care of the roof elements.

Usually the decay of historic roofs roughly depends on two main factors: the leakage from the coat of the roof and the dysfunctions of the main structure, due to major displacements or material damage. Maintenance planning always depended on the recognition of the damage, following more or less detailed visual inspections.

Today the leakage of historic roofs is often resolved with the introduction of waterproofing membranes; these membranes have increased the weight of the roof and reduced the transpiration of the roof, but have substantially guaranteed a complete waterproofing and protection, in such a way that well-preserved historic roofs are now more durable than the past, not having the necessity of ensuring waterproofing through discontinuous elements like tiles. Nevertheless, one problem of the roof is still the collapse of the original small sealing bricks or stucco pieces onto the space underneath, especially with the absence of false ceilings, which have a protection role until a certain point; the fall of small elements, even if restricted to little areas, can be extremely dangerous in rooms and halls occupied



by a large number of visitors. This safety aspect that in the past was tolerated, nowadays is not accepted. For this reason, any little fall must be avoided with frequent inspections of the roof.

THE SURVEY PROCEDURE

For the assessment of the roof, a survey procedure has been set up, tested and developed by subsequent approximations in different case studies. The case studies are represented by a set of important churches in Bologna, all built between the 16th and 18th centuries, whose pitched roofs are supported by timber trusses. The most interesting structures belong to the Cathedral of San Pietro, the church of San Salvatore Maggiore, the church of San Giovanni in Monte, the Basilica of San Petronio and the Basilica of San Domenico. These buildings are built in the same period and some of their naves have unusually big dimensions the trusses of San Pietro were possibly the biggest in Italy – and perhaps in Europe – at the time of construction.
The procedure should follow a preliminary visual and technological survey of the roof but in some occasions, it is the only way of carrying out the preliminary analysis if the structures are not safely accessible. The procedure can be graphically summarized in a synoptic diagram that represents different steps. The method takes advantage of the feedback from the case studies, but can be easily adapted to different contexts. (Fig.03)
The first step is data acquisition, followed by a rendering phase, which provides many outputs (photos, drawings, diagrams and models) which represent the operative tool for the interpretation of the behavior of the studied building. The interpretation of the results allows to depict coherent structural configurations, disengaging them, where necessary, from usual and standardized techniques.
The method has been developed through its application in different case studies, in which 3D surveying instruments and reverse engineering techniques have been used. Reverse engineering is the detailed analysis of a real object aimed at producing or modeling a new object with similar characteristics. Starting from a prototype, or an object that needs to be reproduced, the process of reverse engineering has the goal to derive reference vectorized models. The models are used to carry out dimensional analyses, replace existing parts, and eventually develop completely new parts with improved efficiency.
In the acquisition phase the object of interest needs to be first identified. Depending on the equipment, a preparatory inspection is essential to plan the phases of survey properly and become familiar with these spaces which are often difficult to access. Once the inspection has verified the feasibility of the survey, the scan session is carried out using a laser scanner. For the churches we used the scanner FARO CAM2 FOCUS 3D. This

Figure 3: Synoptic diagram of the procedure: data acquisition phase through laser scanner (yellow), rendering and analysis of the point cloud data (red), output (blue) and achieved results (green).

lightweight and easy to use instrument provides fast scans with an acceptable precision. In fact, the possibility of using a targetless technique minimizes the preparatory activities and the dead time between each scan station. The conclusion of the survey is followed by the phase of spatial data consolidation, performed in back office: the stations are aligned to generate point clouds, a true metric dimensional information repository of the detected object, to which documentary and photographic information can be associated. The consolidated dataset helps to ensure the traceability of data.
The rendering phase leads to three different actions, that are independent but logically consequential: the qualitative analysis, the digital modeling and the quantitative analysis. Each of the three stages is associated with specific outputs (blue boxes in figure). The information related to these outputs can be stored independently or managed into a BIM model.
The qualitative analysis involves the careful observation and understanding of the acquired data, and shifts all considerations to back office. The digitized spatial data are always completely available and it is not necessary to come back to the survey site to retrieve forgotten information. This analysis allows to identify the specific nature and complexity of the roof under investigation, avoiding what might be called reductio ad unum, that is the representation of a single parts according to simplified schemes, whereas there might be slight but significant differences within the same roofing system. Through the direct observation and the extraction of orthophotos from the point cloud an abacus and an overall picture of all the nodes of the different trusses can be drawn up.
Some considerations can also be made on the state of conservation of the structures, identifying the areas where other tests should be made with non-destructive methods, in addition to laser scanning: identification of wood species, determination of wood moisture content values and moisture gradients, determination of strength grade or strength values to be used in the structural analyses, characterization of biological damage.
The digital modeling phase follows the first qualitative assessment of the roof and gives a very detailed representation of the object of the survey: 2D drawings can be traced through operations of vectorization of the orthophotos and the amount of spatial data collected is useful to create 3D models. It is possible to transform the point cloud into 3D models of all trusses using parametric modeling tools with generative algorithms.
After extracting from the project point cloud only the portion representing the truss object of study, some clipping boxes are created in strategic positions close to the knots. Size and orientation of the boxes vary according to the sectioned elements, remaining as orthogonal as possible to each section. These cross sections are exported in the software Rhinoceros. Exporting takes place at the original coordinates of the section without the need to create additional reference systems or to make further alignments. This task is done by keeping fixed the reference system of the global point cloud. After having exported the cross sections, their vectorization is performed automatically using built-in vectorization tools. This is possible because of the extreme simplicity of each cross section and

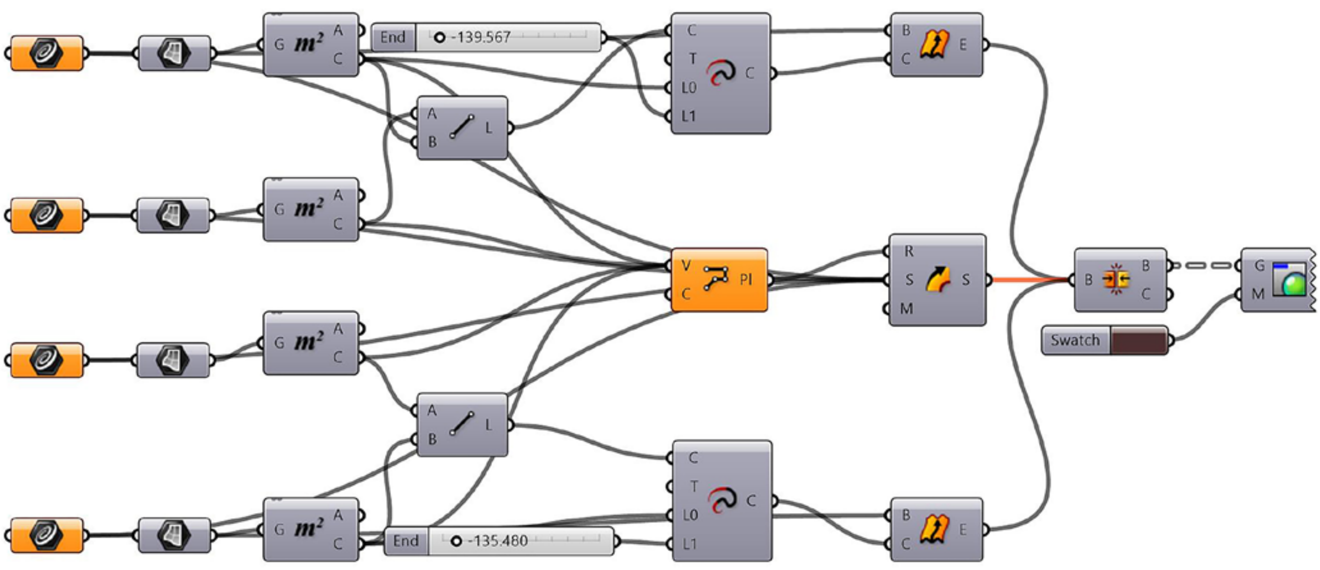
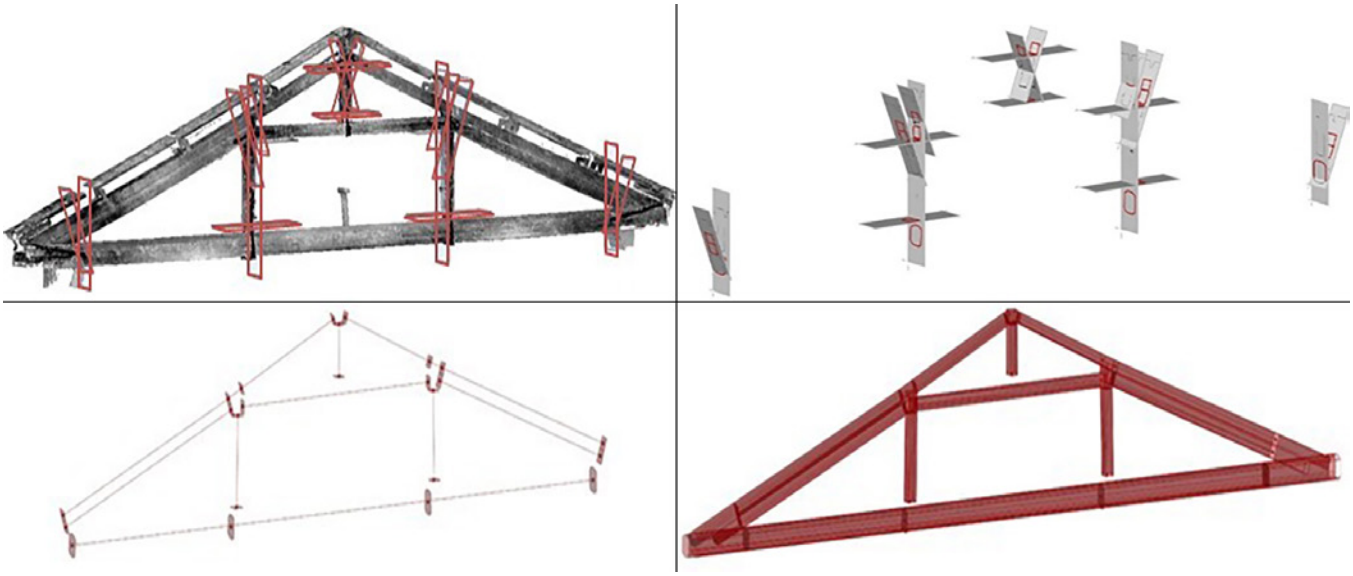
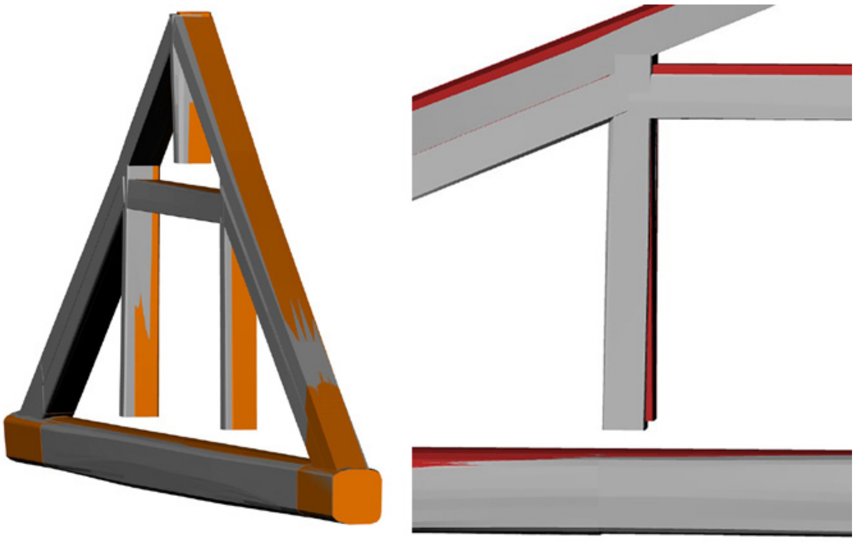


Figure 4: Modelling process of a truss element created with Grasshopper generative algorithms. Each box represents an operation with an input on its left and output on its right. The connections between the boxes indicate the order of the operations. By connecting the outputs of an operation to the inputs of another operation, the result model is automatically generated and it depends on the initial parameters set manually.



the limited number of points. Automatic vectorization or meshing of the entire truss always lead to incongruous models. Therefore, the process of model generation is defined using the Rhinoceros 3D plugin Grasshopper. First of all, the previously obtained section curves are implemented as input parameters. This means that the final output of the entire algorithm depends exclusively on the inserted curves. (Fig.04)
Each box of figure 05, which represents the queen post of the truss of S. Domenico in Bologna, corresponds to one operation. Starting from upper left, the boxes represent the section curves that are the input parameters. Then the algorithm transforms the implemented curves into surfaces (upper right). Once identified surfaces surrounded by input curves, the algorithm calculates their area and the center of gravity and then traces a polyline joining the newly identified centers of gravity (left below). Finally, the algorithm extrudes the sections along the axes defined by the centers of gravity (right below), thus obtaining the 3D profile of each beam. To create knots, section curves are extended along their axis until they intersect another crossing beam. The result of this process is a 3D model representing the truss rendered with a limited number of sections. (Fig.05)
Number and position of the sections used is decided in order to have the best-fitted 3D model with the lowest number of sections. The creation of clipping boxes and orthophotos and the subsequent vectorization represent the most time-consuming steps of the whole method. Using only a few sections strongly affects the speed of the proposed method.
The precise wireframe models can be provided to analyze the behavior of the structures with a finite element calculation software. Furthermore, using reverse engineering software it is possible to compare 3D models with the original point cloud in order to highlight displacements and deformation in every element of the truss.
In fact, the spatial data can be used to create inferred 3D models through a simplified rectification of the rods and the identification of an “ideal truss”. This ideal 3D model is the one that best represents the initial, undeformed condition, and can be used as a BIM model to provide a basis for systematic knowledge that is traceable, objective, comparable and available at any time. This operational method is not linked to any standardization and can consider the specificities of each construction. Subsequently, it is possible to make targeted suggestions for maintenance strategies in order to extend timber trusses service life. Outputs can be considered also as a new starting point for the roofing from which to monitor its behavior over time. This approach favors even the sustainability of maintenance in terms of reversibility, compatibility and proper use of current techniques.
The ideal 3D model is conceived with the aim of analyzing the current static condition of the truss in such a way as to be able to highlight all undergone changes during its service life. Achieved data are used to interpret the behavior of the structure in terms of displacements and deformations. While not having available data on the truss original condition at the time of installation, a series of theoretical assumptions has to be made in order to proceed with the construction of this model. The basic principle is to bring the basic 3D model, to a pre-condition without displacements and deformations. In other words, to what it is supposed to be the original condition at the time of construction.
First of all, all members forming the truss are brought into a single perfectly

Figure 5: : a) The red rectangles indicate the clipping boxes used for the sectioning of the cloud. b) Traces of the sections obtained directly from portioned point cloud are highlighted in red. c) Surfaces created by the algorithm from the previously obtained sections and their connection through each section’s barycenter. d) Result of the modelling process.



vertical plane passing through both the supports of the tie beam. This decision is justified by the fact that supports of the tie beam on the masonry walls are comparable to fixed points. Therefore, it is assumed that the displacements occurred in correspondence of the supports are negligible and consequently that the vertical plane of the truss passes through these points. The orthogonality of this plane is assumed by virtue of the fact that the truss was supposed to be built perfectly planar.

Once having identified the ideal vertical plane, passing through both the supports of the truss, all the centers of gravity of the vectorized sections are projected into this plane. In this way, a perfectly planar structure is modeled, which highlights the occurred displacements from the plane itself. Figure shows how the basic 3D model, in gray, tends to come out from the plane defined by translated vertical model, in orange, highlighting rotations outside the truss plane.

Next, the rectification of each truss member is carried out. The main purpose of this step is to highlight further deformations and displacements not identified by previous steps, especially due to bending moment. This process is performed using Grasshopper algorithms. First, the modeling of each member is made with only two vectorized extremity sections to obtain straight elements. In order to rectify all the edges, the members have been rotated as to reach mutual orthogonality. This step is carried out aligning the center of gravity of the vectorized sections at the free extremity of the member, with the straight perpendicular line passing through the center of mass of the vectorized section at the fixed end of the same member. Figure 06 shows how this operation puts in evidence the members of the rectified 3D model compared to those of the basic 3D model, highlighting the rotations occurred.

After having been rendered, the detailed 3D models of the current geometry of each truss and the detailed ideal 3D models of the undeformed original situation are overlapped to highlight the dimensional differences. This step is carried out using the reverse engineering software Geomagic Control

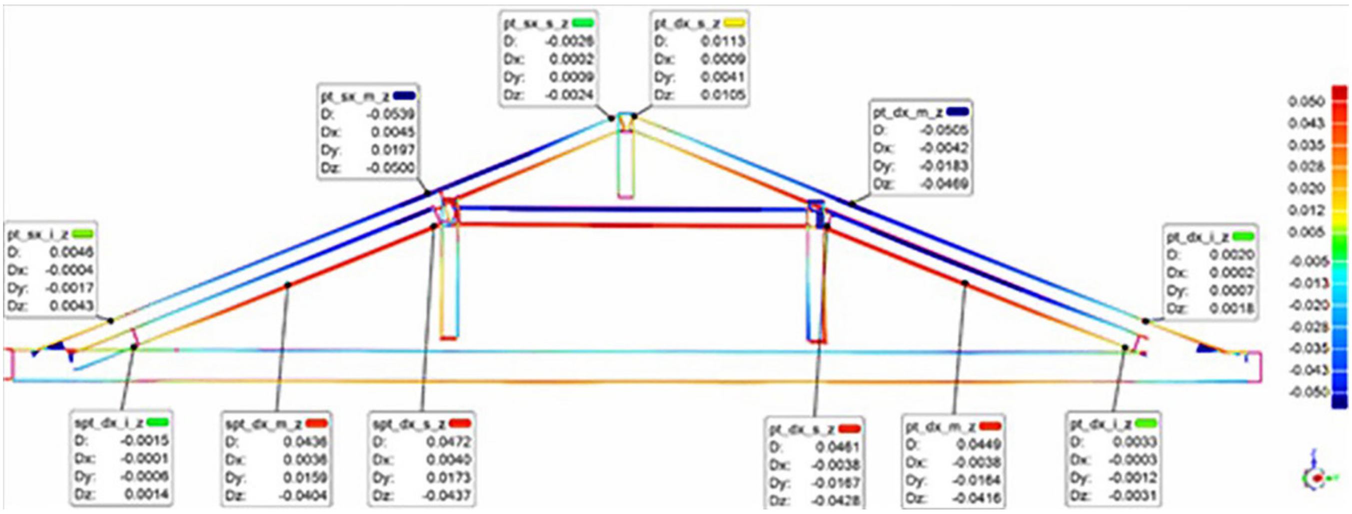
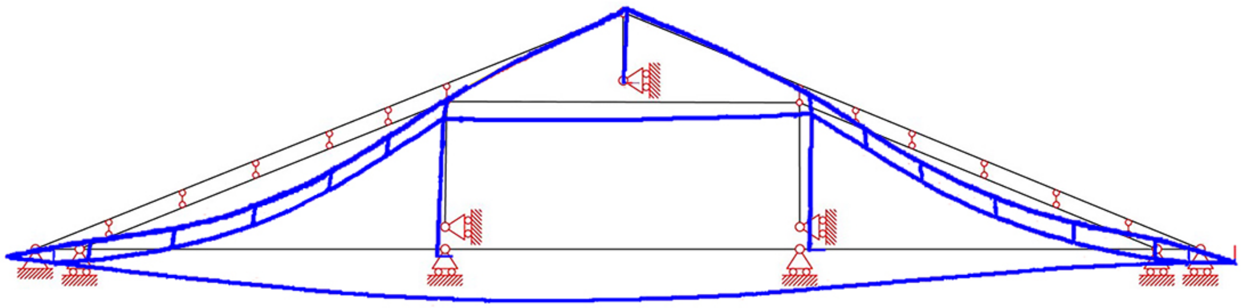


Figure 6: a) Highlighting of the displacements of the truss by overlapping the base model represented in grey with the one obtained from the projection of the sections to the trusses' perfectly vertical plane represented in orange. b) Highlighting the deformations by overlapping the base model represented in grey with the one obtained from the projected and linearized elements represented in red.

Figure 7: Detailed and theoretical model overlapped: two-dimensional section on yz plane with annexed annotation of the displacement values on the most significant control points. The deep blue and red colors represent the interval between 5 and 7 cm.



that is able to examine and graphically report, in chromatic scale, the deviation between every corresponding points of the compared trusses. Minimum and maximum deviation threshold to be detected is set manually, in the chromatic scale, in order to have a better indication about the order of magnitude of dimensional differences between trusses.

It is possible to select any position on every member of the truss in order to highlight locally the numerical value of deviations by means of a 2D graphical representation. This interpretation provides both qualitative and quantitative information and eases an accurate and widespread understanding of the displacements and deformations life of each truss. All movements and deformations that each truss underwent over time in the entire roofing.

Moreover, lowering and rotations of the king and queen posts can be analyzed and highlighted locally, as well as torsional phenomena or rotations of the tie beams, lowering of bearings and bending of rafters, and eventually deformation phenomena withstand by the whole roofing.

Comparisons can be made between two complete 3D models, and on 2D projection planes selected by the user depending on the kind of truss member and on the type of deviations that have to be magnified. The software itself allows, in addition to the deviations' graphical representation, a precise quantification them using control points. By using the annotation tool, it is possible to report the exact value of the distance measured between the corresponding points of the two compared models and its decomposition along the x, y and z axes. (Fig.07)

An aspect that is considered in the structural analysis is the long-term dimensional deformation due to hygroscopic phenomena. The viscosity of the timber trusses must be taken into high consideration, because it is responsible of creep and potential failure of the structure over the long period. The deformation due to viscosity is detected through the above-mentioned operations, starting from the geometry of the "ideal truss".

The shrinkage coefficient due to humidity under the saturation point is expressed by the formula:

$$\varepsilon_{LRT} = \frac{\Delta L_{LRT}}{L_{LRT} \times \Delta\mu} \times 100$$

where Dμ is the time-dependent variation of moisture in wood. Applying the effect of moisture in the FEM model of the truss, it is possible to make a confrontation between the ideal geometry and the actual configuration, evaluating the long-term deformation due to mechanical loads, temperature and humidity. (Fig.08)

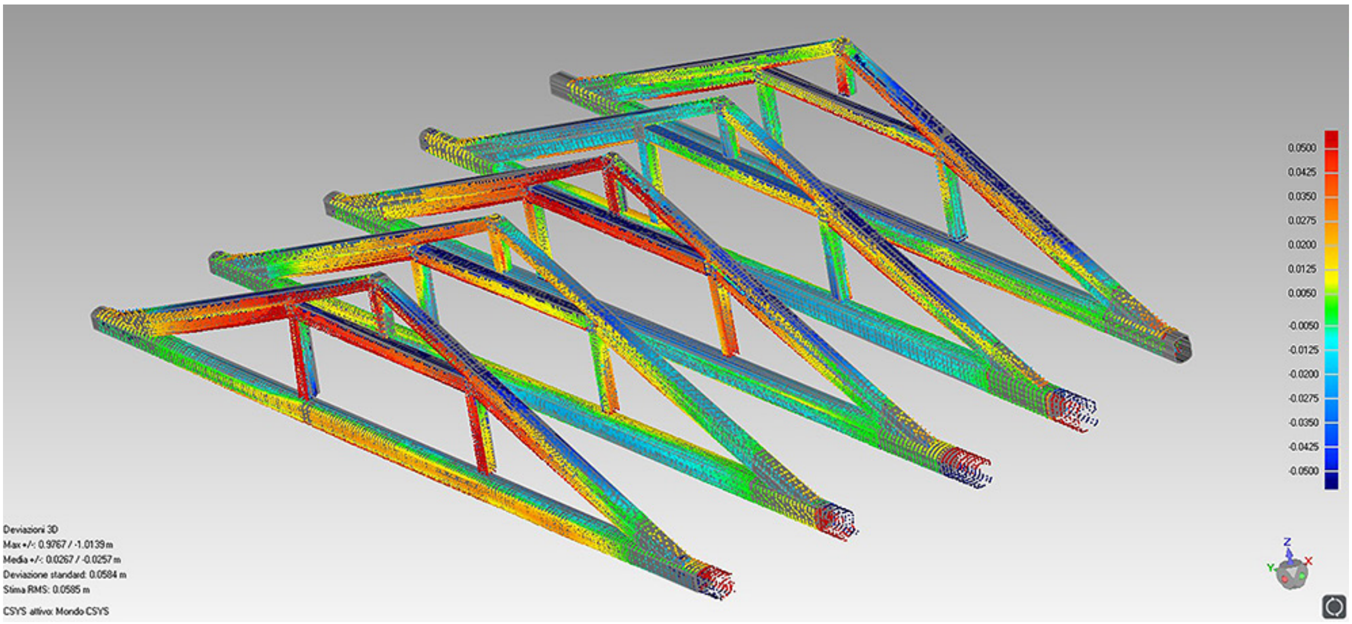
DISCUSSION

One possible future development regards the refinement and the simplification of the whole procedure; for instance, the creation of the BIM model is still under implementation. (Fig.09)

The final goal of the procedure would be to operate the comparison between deformations in the Rhino model and the deformations in the structural model in a BIM environment.

Exporting static geometries is working fine from Rhino but when it comes to a BIM workflow simply exporting is not enough. Static geometries won't intersect with native elements and are difficult to enhance with parameters. Redrawing geometry with native BIM elements often seems to be the only solution. But then, any design change is forcing you to repeat. Open source software like Grevit or GeometryGym creates BIM elements from Rhino and also allows the designer to update BIM elements later according to latest design changes while all parameter values remain in place. A designer working in Grasshopper can send their geometries to one Revit instance. In fact, it is possible to use curves scripted in Grasshopper to create numerous native BIM elements inside BIM software (Fig.10). The aim is to generate a federated BIM model using computational BIM workflows starting from Rhino/GH. With the tightly coupled approach, systems are coupled through the Application Programming Interface

Figure 8: Deformations in the structural model.



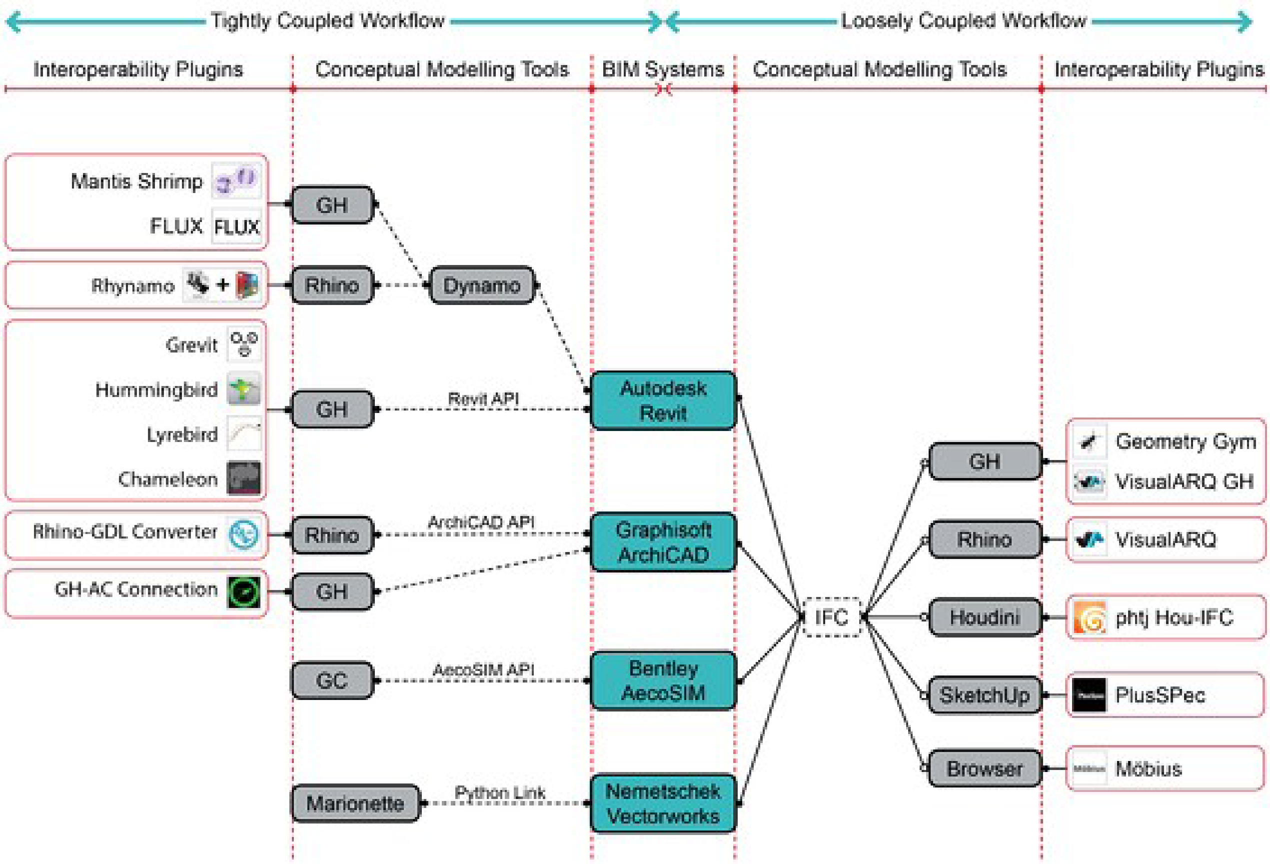


Figure 9: 3D model to be translated into a BIM model.
Figure 10: Computational BIM workflows that are in use today.

(API) provided by the BIM system. In this case, graph-based systems communicate via the API of the BIM system, directly instantiating geometry in the BIM model each time the graph-based model is executed. With the Loosely Coupled approach, systems are coupled through model exchange. The graph-based system typically generates data in a standard file format that can be directly imported into the BIM system. (Fig.10)

CONCLUSIONS

The geometrical results have led to a better comprehension of the displacements and the deformations of the elements. In most of the cases the results of the structural models were confirming these long-term deformations due to moisture; in general terms it was possible to detect the general shrinkage and relaxation of the structural systems over time. For instance, many brackets of the king posts were not able to perform the original task of supporting the tie beams. In some and active systems were conceived to stop or, at least, slow down this natural process of viscous deformation. In a few cases rotations of the joints and the elements were detected: in these conditions the necessity of replacing weak or displaced elements or reinforce the joints was reported. The method that has been defined will be implemented into a BIM software to be used for the life cycle planning of the roof structures. In fact, it is possible to repeat the same analysis after a few years, detecting the variations. With this procedure it is possible to monitor in time the deformation of the roof, selecting deformation that cannot be seen in a global vision; while in the past deformation could be observed locally, in such a way it is possible to detain displacements in a whole perspective, locating the tendency of the roof, and, especially, the speed of the deformation over time; confronting two models in a reliable space of time, like 7-10 years for instance under normal conditions, it is possible to detect different positions. In such a way the maintenance costs can be better evaluated. It is obvious that this deep analysis should not substitute a material and local survey.

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15

BIM-Based H&S Management for Facilities. Operations & Maintenance of Logistic Plants

KEYWORDS: Industrial plant, Facility Management, Health and Safety, BIM

Over the years, international researches about Facility Management has become increasingly important, also thanks to the advent of the BIM methodology which integrates information from all phases of the process, and closes, ideally in a circular way, the life cycle of a building. Within the abundant maintenance operations of the buildings characterizing the Facility Management phase, one of the important aspects is the H&S planning and management for operators and maintenance technicians. This research uses a dynamic BIM-based approach for Health and Safety management during O&M phase, connected to the programmed maintenance cycles, for a historical industrial plant.
The case study presented is the former Fiat plant in Rivalta (TO), currently being converted into a warehouse and logistics facility by the FCA Group. Information comes from the project documents, from the Building Maintenance Plan and from the H&S Maintenance dossier of the building installations should linked together. All of them are going to constitute the information component (LOI) relating to the BIM object. During the construction of the BIM model, the position of each object is valuable information, fundamental for the right choice of equipment and fittings necessary for the correct execution in safe, of maintenance operations. The safety of workplaces is related, for example, to access procedures to intervention area or to the correct selection of fall protection systems.
First, an analysis on information necessary for the management of a safe O&M in a BIM environment is carry out. BIM should not be only a digitizing way for work's file, it's not only a sheet containing processes and procedures identified by the safety coordinator; BIM, in this area, can be used as intelligent tool for risk assessment and, consequently, a methodology that can be used for choosing the most appropriate systems, in order to safeguard the workers H&S.

INTRODUCTION

In the context of the abundant building maintenance operations that characterize the Facility Management phase, one of the important aspects is the planning and management of the health and safety of operators and maintainers. The aim of this research is to use the dynamic and intelligent approach based on the BIM for the management of Health and Safety in the O&M phase. In the literature there are many papers and researches in which BIM is used for the management of the maintenance phase (Kasprzak & Dubler, 2012) (S. K. Lee, An, & Yu, 2012) (Yalcinkaya, Singh, Fukuda, Bernard, & Gurumoorthy, 2014) (Arayici, Y, Onyenobi, TC and Egbu, 2012) and many papers in which BIM is applied for the management of H&S in construction sites (Zhang, Teizer, Lee, Eastman, & Venugopal, 2013) (Getuli, Ventura, Capone, & Ciribini, 2016). It is very rare, however, to find research that deals with both these topics (Wetzel & Thabet, 2015), some who deal with all that is contained in the H&S Maintenance dossier, drawn up by the safety manager; in other words, on the BIM used to design the safety management of operators during the maintenance phase, which covers the entire life cycle of the building.
The idea is to use the possibilities provided by parametric modelling to create a BIM H&S Maintenance dossier in which the safety equipment is chosen according to the position of the object to be maintained. The proposed theory is applied to scheduled maintenance cycles for a historical industrial plant. The case study presented is the former Fiat plant in Rivalta (TO), currently being transformed into warehouse and logistics by the FCA Group. The information comes from the project documents, the Building Maintenance Plan and the H&S Maintenance dossier of the building installations, which must be linked together. During the construction of the BIM model, the position of each object is a precious piece of information, fundamental for the correct choice of equipment and fittings necessary for the correct execution of maintenance operations in safety. The safety of the workplace is linked, for example, to the procedures for access to the intervention area or the correct choice of fall protection systems. In this context, BIM can be used as an intelligent tool for risk assessment. In fact, it is a methodology that can be used to choose the most appropriate systems, in order to safeguard the health and safety of workers.

BIM AND FACILITY MANAGEMENT

The O&M phase, which is part of the more extensive FM domain, covers the longer time period of a building's life cycle. Even when costs are taken into account, the FM phase generates most of the costs (S. Lee & Akin, 2011) and represents approximately 85% of the total costs of the building's life-cycle costs (Eastman, Teicholz, Sacks, & Liston, 2011). Related with this in the literature we find different data, for example, for buildings used for industrial purposes, it is estimated that the cost attributed to maintenance activities varies between 15 and 70 percent of total production (Muthu, Devadasan, Ahmed, Suresh, & Baladhandayutham, 2000). Other studies show that the total life-cycle cost of a project is 5 to 7 times higher than the initial investment costs (S. K. Lee et al., 2012) and 3 times the cost of construction (BIM Task Group, 2012).
Maintenance makes an important contribution to the maintenance and improvement of plant and equipment, product quality and safety requirements and, for this reason, forms a significant part of the operating budget of companies (Al-Najjar & Alsyouf, 2003). In addition, as the complexity of technological systems increases, maintenance costs have increased three times in ten years, from $200 billion in 1979 to $6,000 billion in 1989 (Wireman, 1990). In view of these data, it is not surprising that a

significant effort is made to use the BIM methodology in the O&M phase. The BIM is in fact a digital representation of the construction process that facilitates the exchange of information between those involved in the different phases of building screws. While BIM has been used mainly for the design and construction phase, due to the speed of visualization and coordination between disciplines, there is a growing interest in using BIM in FM activities (Fraser, 2014).

INFORMATION FOR SAFETY MANAGEMENT IN THE O&M PHASES

In the Italian context, safety management, even in the O&M phase, is entrusted in the first instance to the Safety Coordinator during the design phase, who prepares the work file, a document that provides, for each type of work, the preventive and protective measures in the building or the measures necessary to carry out maintenance. The H&S Maintenance dossier of the building installations is structured in sheets, which try to summarize the necessary information, inserting the appropriate references to the documents in which the technical information of the project is contained.

This document is regulated by Article 91, paragraph 1, letter b) of Legislative Decree 81/2008, which provides its structure in three parts: Chapter 1: Summary description of the work and indication of the parties involved, Chapter 2: Identification of the risks, preventive and protective measures endowed with the work and auxiliary measures, for foreseeable subsequent interventions on the work, such as ordinary and extraordinary maintenance, as well as other subsequent interventions already planned or planned, Chapter 3: References to existing support documentation. Annex XVI contains a standard structure of the forms to be filled in.

One of the habits is to fill in a form for each type of work, typically defined as the work to be carried out on site. Going into more detail about the contents of the sheets you can see that much of the information for the proper management of safety are related to the location and safety of the workplace where you will go to work. For this reason, a single sheet describing the preventive and protective measures for the maintenance of a luminaire can be extremely dangerous because the same lamps may have been installed at different heights or in places with different interference risks.

The procedure described in the decree provides for the updating of the file by the Safety Coordinator during the execution phase, which must keep it updated with respect to the evolution of the site and the changes made in the construction phase. Often, however, the existing sheets are updated, without customizing the risk assessment based on the exact location of the object in the building, leaving the operator the burden of recovering the project tables (stored in the offices), identify the preventive and protective measures prescribed by the CSP / CSE.

Let's not forget, in this consideration, another document, complementary to the H&S Maintenance dossier of the building installations: the maintenance plan of the building. It contains details of the maintenance operations to be carried out on each individual component, in relation to the specific product present in the building, as indicated by the manufacturer. In this document, for example, we find a very important information: the frequency of maintenance. Both documents will be managed and updated throughout the use of the building by the person in charge of maintenance and, as far as safety responsibilities are concerned, by the RSPP (Head of the Prevention and Protection Service).

CASE STUDY

The FIAT production plant in Rivalta, built about 10 kilometres from the Fiat plant in Mirafiori, is one of the historic buildings of Italian automobile production since the second half of 1967. The factory started from a building intended for mechanical processing (assembly of the suspensions of almost all Fiat models). In the short period of a year, further structures were built for the assembly of the bodies, for the slabs, for the painting and for the finishing of the cars.

The buildings, for the last two processes, were built on the opposite side of the above mentioned provincial road. An aerial road conveyor, crossing the street, ensured the connection of all the assembly lines in a bilateral sense. All the other connections, both pedestrian and by wheel, were sent back to an underground tunnel.

In 1973, another large industrial structure was built, in continuity and combined with the slab line, to house the large presses: the latter were considered inadequate for the old operating site (near the civil buildings in the Mirafiori area). Since 2002, part of the plant in disuse (to be precise, the Operating Assembly Unit) has been redeveloped and organized for the production of components. A Turinauto moulding centre and Magneti Marelli suspension systems remain active at the automotive level. In February 2018 the Fiat Chrysler Automobiles group announced the reuse of the Rivalta plant, through the deposit at the local municipality of a project that provides for the development in three years of an area for a total of 340000 square meters of which 40000 dedicated to the construction of new facilities for logistics and spare parts for the group.

The conversion of buildings B, C, D and F into a logistical warehouse and the refurbishment of a new building Z and the car storage area (former track). Currently, the demolition and dismantling of the existing systems, the asbestos reclamation and the construction of new works and technological systems are underway. Pavilion D was modelled.

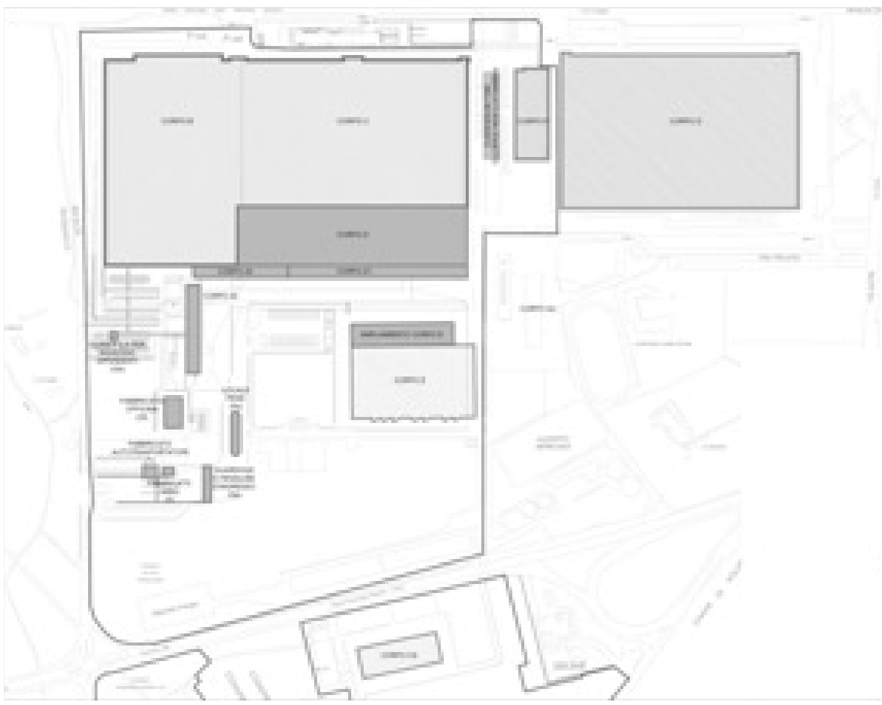


Figure 1: Vista aerea dell'Ex Stabilimento FIAT di Rivalta (TO) (https://it.wikipedia.org/wiki/Fiat_Rivalta)
Figure 2: Plan of the FCA industrial district of Rivalta. The conversion of buildings B, C, D and F into a logistical warehouse and the refurbishment of a new building Z and the car storage area (former track). Currently, the demolition and dismantling of the existing systems, the asbestos reclamation and the construction of new works and technological systems are underway. Pavilion D was modelled.

THE BIM FOR THE PREPARATION OF THE H&S MAINTENANCE DOSSIER OF THE BUILDING INSTALLATIONS

The H&S Maintenance dossier of the building installations is an extremely important document, which contains all the information needed to safely carry out maintenance and intervention on the building. It is generally structured in cards, dedicated to each work that is expected to be carried out on the building or on parts of it. These sheets, defined in Annex XVI of Legislative Decree 81/2008, identify the object of maintenance and the type of intervention, together with the risks that the Safety Coordinator identifies for the operators. To these first data are necessarily attached a series of information that identify the technical characteristics of the planned work and the place of work.
Usually there is a general reference to the project tables; the third part of the dossier, in fact, obligatorily contains the list of the technical documents and their placement in the archive to help the operators who will have to intervene during the phase of use and maintenance of the asset. The main information to be retrieved is the context in which the work is located, the architectural and static structure in which it will operate and the systems installed. This series of references does not facilitate the workflow and makes it much more difficult to find information, especially if you think that it is often a matter of extraordinary maintenance or emergency situations.
Contains references to the products used, links to the technical sheets and the approval reports of the Works Director. But above all with the model you can see the context and allows you to evaluate the most suitable preparations to intervene ensuring the safety of operators.

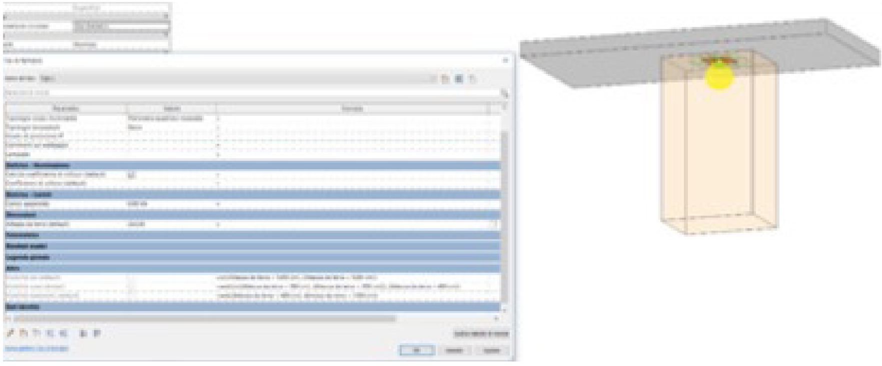
THE CHOICE OF EQUIPMENT FOR FALLING FROM A HEIGHT

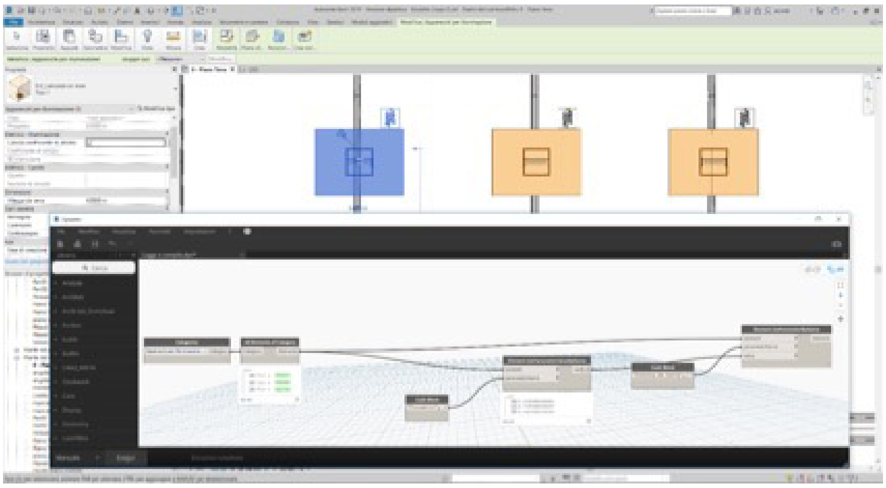
As we have seen before, one of the choices that the Coordinator must make when drafting the Work's file is the definition of preventive and protective measures regarding access and the workplace. In the case of work at a height, it is necessary to provide for the use of suitable equipment that allows maintenance operations to be carried out on plant or building objects laid at a height, safeguarding the health and safety of workers and taking into account the surrounding area.
The proposed system provides for the definition of general rules for the choice of the most suitable equipment, in relation to the height above the ground of the element being maintained. An example has been realized just on one of the lamps placed inside the hall of Rivalta. The rules inserted in the model allow to compile the parameter "height from the ground" through a Dynamo script.
This parameter identifies, according to appropriate thresholds, which will be the most appropriate preparation to be used and represents it, both next to the object in the documents to be printed, and identifies the area that must be free, necessary to safely perform the work.
The limits identified in this example are:
Together with the symbol that represents the most suitable preparation, all the useful information for the use of the same could be attached. For example, all the instructions regarding the correct use, the necessary PPE, the mandatory

Range	*Proper Equipment*
2 m < height from ground < 4 m	*Use of the ladder*
4 m < height from ground < 8 m	*Use of folding mobile scaffold*
8 m < height from ground < 12 m	*Use of lifting Platform*

Table 1: Limits range for the proper equipment choice
Figure 3: Photos of the interiors of the FCA industrial district of Rivalta (http://www.studio-aea.it/realizzazioni.html?rel_id=23)

measures to be put in place before working on the object. For example, in the case of a study, a very useful piece of information is the reference to the EQ to be deactivated. Currently, this information should be sought in the as-built tables, a work that is often replaced by attempts or tests on site.
In the three-dimensional view, or in the navigation inside the model with the augmented reality, it is possible to visualize the encumbrance of the preparations, chosen in relation to the height from the ground.
This system makes it possible to identify very quickly where there may be problems of interference between objects. It is in fact immediate with the Clash Detection systems to see if, in the presence of other objects, such as shelves or systems, the planned preparation can not be used and, consequently, other systems must be imagined to allow work at height in safety.
The BIM is an obvious example of the now common habit of not treating each workplace specifically. The worksheets are completed with general information, which does not meet the actual needs of maintenance workers, who are forced to improvise each time, increasing the risk of accidents at work.





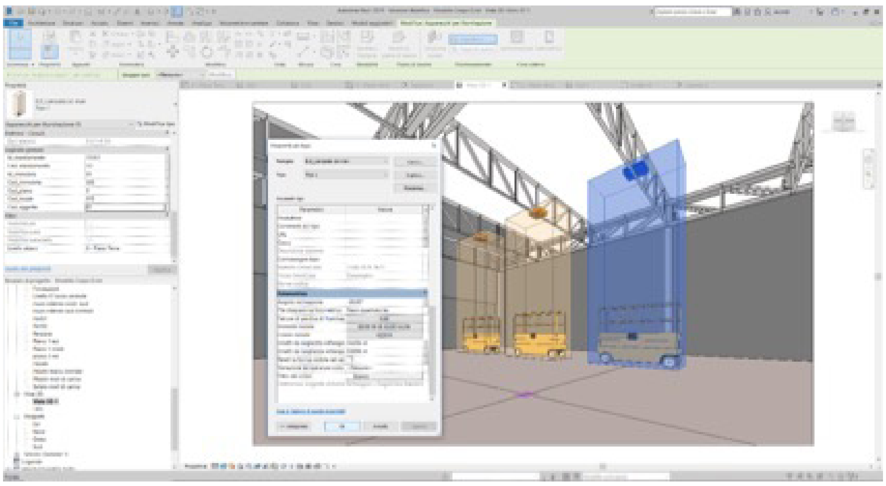


Figure 4: BIM Parametric family with different displays depending on the "height from ground" parameter (V. Villa)
Figure 5: Screenshot of the Dynamo script for the automatic compilation of the parameters in the families, and visualization of the indication of the most suitable preparation and the area necessary to carry out the maintenance. (V. Villa)
Figure 6: Screenshot of the three-dimensional view of the BIM model that displays, based on the parameter "height from the ground" of the object to be maintained, the preparation for the most suitable security. (V. Villa)

CONCLUSIONS

While the BIM for Facility Management has a good bibliography in the literature, the focus on security management during O&M operations is still little analyzed. The multiplicity of information, deriving from different documents because of the competence of different subjects, often leads to improvise the methods of intervention. Improvisation, together with the unavailability of information in the place where the operating teams are operating, leads to the occurrence of accidents at work. The proposal defined in this paper, although embryonic and to be developed in the course of future research, proposes a system for sharing information within the model, looking for rules for the definition of PCDs and IPRs needed according to the workplace. Future developments are broad and include, for example, the examination of work on roofs and work in confined environments, historically among the first causes of death during operation and maintenance.

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16

A Project Framework to Introduce Virtual Reality in Construction Health and Safety

KEYWORDS: Health and Safety, Virtual Reality, BIM, Workers' Training

Building construction is considered a complex, dynamic and highly hazardous process which embraces many factors that are potentially dangerous to workers. Many studies proved that the improvement of preventive and proactive measures -dynamically included in the building design, planning and construction- could reduce site accidents as well as increase the site productivity.
In this context, process management models and information visualization techniques such as Building Information Modelling (BIM) and Virtual Reality (VR) seem to be devoted to strongly contribute to the advancement of the current safety management practices. For this reasons, the presented contribution starts with a short review of the adoption of BIM and BIM-related digital technologies for risk management together with VR application for Construction Health and Safety which aim to generate immersive environments from which workers can experience safe insights into the way the real construction site works.
The main objective of this contribution is to review existing proposals in this field of construction health and safety as related to ICT technologies, especially BIM and Virtual Reality, in order to propose, at the end, a project framework able to guide future researches and applications on the use of BIM-enabled Virtual Reality for Safety purposes for site design validation and related workers' training.

INTRODUCTION

OHS in building construction

Even now, construction Occupational Health and Safety (OHS) remains a worldwide problem in terms of workplace injuries and fatality statistics as is shown from OpenData 2018 of the Italian National Institute for Insurance against Accidents at Work (INAIL) (INAIL OpenData 2018) with an increase by 1,6% to 20.039 reported accidents and 682 fatal ones.
In this context, what is important is to look at the root causes in order to develop appropriate research and innovative applications able to realistically influence and increase safety culture throughout the project life-cycle, from the design phase to maintenance. Such causes may be inferred from the findings of the "CNCPT 2017 Report" (Activity Report CPT 2017) about safety in construction sector where CNPT has monitored 23.117 construction sites with 48.294 site inspections amounting to 14.987 construction companies involved. The instances of non-compliance in the application of the Italian HS regulation in the aforementioned inspections can be classified as follow in order of decreasing amount:

1. extensive lack of warning signals for the identification risk zones,
2. lack of site personell having specific safety tasks;
3. lack of education in terms of site planning and coordination;
4. shallow risk analysis inconsistent with the specific construction site.

What emerges from this report is an important lack of contents, quality and details in the safety plans with negative safety implications in the entire construction execution that is often delegate to the foremans' improvisational capabilities and their on-site experience. This is also due to the fact that most of those plans are usually provided with a set of instructions in the form of texts or two-dimensional drawings often difficult to be fully understood by site technicians and even more by site workers.
Nowadays, as reflected in literature (Martinez-Aires et al. 2018), there are many proposals that use new models and technologies to assist safety management tasks and, more specifically, Building Information Modelling (BIM) and BIM related technologies seem to be to the most advocated to increase safety performance.
Given these circumstances, the main objective of this contribution is to review existing proposals in this field of construction health and safety as related to ICT technologies, especially BIM and Virtual Reality (VR), in order to propose, at the end, a project framework able to guide future researches and applications on the use of BIM-enabled Virtual Reality for Safety puroposes for site design validation and related workers' training.

BACKGROUND

Increasing use of ICT for safety purposes

Several studies show that Information and Communication Technology (ICT) is often advocated to contribute to safety and risk management. In the following section, an overall view of the research trends and applications is provided:

1. Knowledge based systems: systems and models that take into account data and experience from previous projects in order to support decision making for risk assessment. The integration with BIM in terms of information source (Motamedi et al. 2014) and a digital environment to share knowledge among site managers and engineers has been proposed (Qi et al. 2011).
2. Automatic rule checking: design assessment based on the use of computer programs to asses a design and objects configuration with regulations via specific algorithms and BIM-compliant platform (Eastman et al. 2009) (Getuli et. al 2017).
3. 4D BIM: Construction schedule information integrated into a 3D BIM to increase dynamic visualization of safety procedure.
4. Clash detection: for a safety desing purpose, clash detection is monstly used for construction workspaces planning and management which includes three main research objectives:
   a. generation and allocation of workspaces by using 2D/3D modelling environment able to simulate construction activities' workspaces by using mark-up;
   b. detection of congestion and spatial temporal conflicts in terms of physical conflict among workspaces, temporal overlap between tasks and site congestions;
5. workspaces conflict resolution by using different approaches as mathematical algorithms, artificial intelligence methods or rule-based heuristic approaches.
6. All the aformationed models has been classified as Reactive IT-based safety systems that are able to provide simulation virtual prototyping to assist safety risk identification and safety planning.
7. Moreover, due to the fact that construction projects have a habit of changes during the execution phase, a second group of models, classified as Proactive IT-based safety systems have been proposed in literature. These models, somehow integrated with BIM environments, are able to collect real-time data from the sites for futher analysis and give immediate warning or feedback to the site personells. They are mostly used for:
   h. materials, workers and machines' real-time dynamic position tracking during construction activities;

i. safe machines' navigation in the construction site due to automatic obstacle detection system;
j. positioning sensors such as Radio frequency identification (RFID), Global positioning system (GPS) etc. embedded into Personal Protective Equipments to track workers real time and warn when they enter a hazard space;
k. other proactive technologies such as laser scanning, remote sensing and actuating technology, wireless communication.

12. Virtual Reality (VR) and related technologies that are mainly used for construction education and training which consist of an interactive computer environment able to introduce an external user in a real-time animation simulating the real works. These application can be classified as follow:
13. Desktop-Based VR that displays a 3D virtual world of the construction site environment on a desktop screen without any tracking equipment to support. It relies on the workers' spatial and perception abilities to experience what happens around them. Most of the tasks can be conducted through the use of mouse and keyboard.
14. Immersive VR that relies on the use of special hardware, such as the head-mounted device (HMD) and sensor gloves, to withdraw users from the physical world and provide an environment more immersive and interactive than others techonologies.
15. 3D Game-Based VR. It is an engine able to produce a computer-based video game that provide a interactive virtual-reality of the site environmt also using a multi-user operating technology.
16. BIM-Enabled VR. BIM-enabled VR relies on the model, emphasizing on the data binding and connections behind other VR categories, to simulate construction processes and operations. For example, BIM-enabled VR allows user to take building design into a 3D virtual environment with all relevant building information, experiencing the BIM model in a virtual environment without the restrictions of peering into a 2D drawings, and actually inspecting the designed space.
17. Augmented reality. It uses sensory technology to provide a live direct view of a physical environment with overlapped virtual information.

All the aformentioned technologies have been used for safety training to improve construction site operation safety.
From the above-mentioned background it has been emerged that, despite of considerable development work, most of their focus has been developed for testing or developing new technologies to mitigate safety risks. In addiction, another knowledge gap is that there are nearly no studies investigating how BIM and VR can be simulataneosuly integrated in real projects for site safey management by using a coherent and linear methodological workflow.
For these reasons, in the following section, the authors propose a conceptual project framework which is currently being tested in two italian real projects and for this reason is still copyright protected. The following images are extracted from those projects.

AN HS PROJECT FRAMEWORK

The research assumption, extensively codified in literature on which the proposed framework is based, is the use of BIM both as a systematic construction management tool and as a data source with the object to fill the role of an input driver for others BIM-enabled tools (IFC-compliant) able to run further site simulation or analysis (e.g. 4D BIM simulation). Furthermore, as regards VR technologies, a BIM-based approach has been widely adopted to develop immersive VR experiences for validation purposes at different project stages (Lin et al. 2018) (Du et al. 2018).
Starting from these evidences, a project framework for planning HS workers' training by using immersive VR, integrated in a coherent BIM-based design workflow -which embraces the design, planning and construction stage-, is proposed. The reason for that is twofold:

a. Design efficiency: a BIM model that stores the information required for the Health & Safety management (site phases, layouts, site paths, risk zones, etc.) together with the 3D building geometry and data, is precisely what is needed to generate virtual scenarios and to plan VR training sessions;
b. Process repeatability: once determined a robust BIM-based framework and workflow for delivering immersive VR training experiences, it can be exentesively adopted and repeated in other real construction projects.

As shown in Figure 1, the proposed project framework is composed of three different macro-phases: (1) building design, (2) construction planning and (3) construction execution that are those of a standard project life-cycle. For each one of them a BIM-process HS-oriented and a VR application is set. Their description is reported below:

- Phase 1: Building design

The standard Building Information

Models (BIMs) -architectural, mep and structural- are first amalgamated into a Federated Model. This model is the one dedicated to being validated in a collaborative multi-user VR sessions in which contractor, project manager together with the design team, virtually walking into the building, will be able to examine design solutions from the different perspectives and requirements on functions, work environments, safety and emergencency signs. In order to be ale to use the BIM model as the basis of the VR Model, the IFC Data Format is recommented; otherwise great uncertainty will ensure as the result of an interoperability bottleneck when passing data from BIM to VR applications.

- Phase 2: Construction planning

Having validated and stored the Building Design, it is time to start with the construction site planning. At this step the BIM is enriched with the information required to simulate and analyse the construction process in terms of site progression. According to the H&S Manager experience, the construction schedule, in terms of construction phases and the activities with the relevant Health and Safety data and site objects (e.g. facilities, machineries' position, equipments, scaffolds, labor crews, site paths, etc.) concur to build a complete Site Information Model (SIM). The given SIM is now ready to being exported in a 4D BIM simulation environment in order to visualize the activities progression proposed. In the same way as the previous phase, the HS Manager and others involved practitioners can validate the site plans for each layout in a collaborative multi-user VR session having an immersive experience of the site environment. This "first-person" experience of the virtual site allows to evaluate its feasibility in terms of position of facilities, equipments and machineries; storage areas, materials' input/output paths and workspaces management and risk zones.

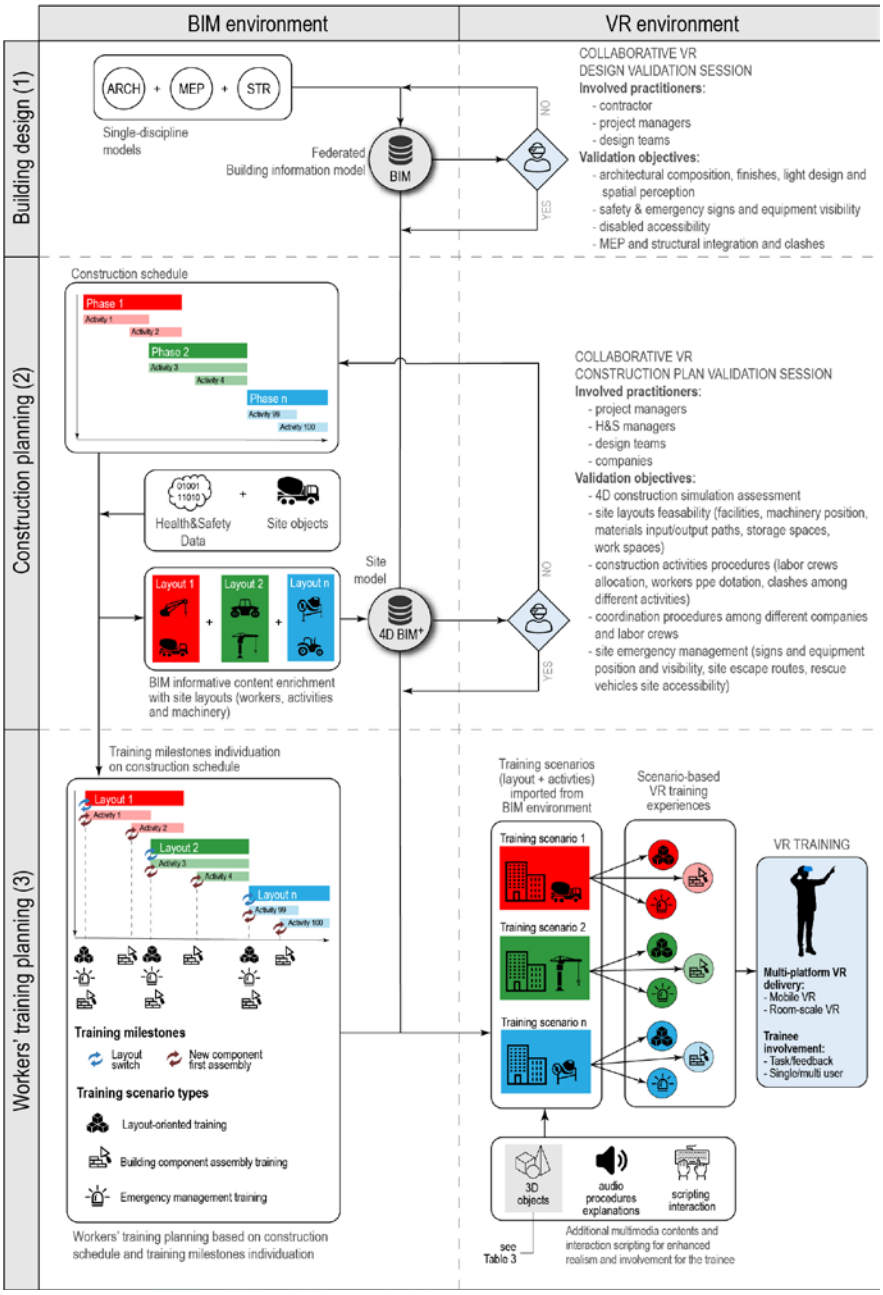


Figure 1: Conceptual project framework for introduction of Virtual Reality in Construction Health & Safety schema

In addition, construction activities -related to specific building objects- should be represented in terms of required workspaces to be constructed in order to be later able to validate safe procedures, personal protective equipments (PPEs) and accidental clashes in a VR site model up to date (see Table 4). An extensive explanation of this approach has been proposed by the authors in (Getuli and Capone 2018). By using this BIM, it is also possible to instantly set and share coordination procedures among different companies and validate site emergency management measures.
Once again, to preserve interoperability, it's crucial to deliver the site information model optimized for VR collaborative validation session in an IFC format.

- Phase 3: Workers' training planning during the Construction execution

At this stage site plans are validated and the project is going to enter in the construction phase. In the proposed framework, the HS manager will use the validated Site Information Model to plan immersive VR training sessions for education and coordination of workers in site.

In the proposed workflow the training scenarios are related to the specific construction site and its time evolution. In fact the input driver of those scenarios is the 4D BIM model and the related site layouts coming from the previous planning phase.
The authors propose three different workers' training typologies with different safety training perspectives (see Figure 2).
According to the proposed training typologies a workers' training schedule can be obtained (see Figure 1). Infact, the HS manager is supported with a simple decision criterion consisting in the individuation of two training milestones upon the construction schedule:

1. Layout switch: when the layout change a VR workers' training session is required;
2. New component first assembly: before the assembly of a building component is performed for the first time in site a VR training session is required.

Once the training schedule is available is necessary to pass to the VR environment to develop the training experiences. In fact, unlike the previous VR workflows in which the VR validation session are usually limited to the first-person exploration of the virtual building, the informative content of the Site Information Model is not sufficient to develop an interactive and realistic immersive experience for workers' training and education. The VR training experience to be effective needs to immerge worker in a vivid, realistic and interactive virtual environment in which he can not only move around but also have interactions with realistic objects, perform tasks and generally be involved in a learning path that drives him to achieving the training objectives. This realism gap in the BIM site model is the reason why the VR model for workers' training should be enriched with extra contents. This is due to the different development purposes between a BIM for site planning and a VR model for safety workers' training .
Infact, while in the BIM approach a low Level of Development (LOD) is sufficient to represent site objects (see Table 1), in the VR Model the realism of the virtual site environment and the ways in which the users can interact with its objects is the core issue for the effectiveness of the workers' experience itself.
To better show this difference in Table 2 is reported a comparison of the same views of a site layout in BIM coming from the Design stage and VR environments for workers' training. The images are referred to the installation of a jib crane.
In the authors proposal, there is no reason to force the BIM platforms to reach an hight Level of Development of the site model. It has to be sufficient for a straight VR implementation. The given BIM is infact used as a base reference in terms of machineries position, risk zones identification, storage areas allocation and so forth.

VR Training typologies		
Layout-oriented training	When [milestone schedule]	Before each site layout transformation [layout switch]
	What	- Activities coordination and workspaces management - Workers', materials' and vehicles' site circulation - Facilities and site zones access and usage authorization
Building component first assembly training	When [milestone schedule]	Before every first assembly of a new component [new component first assembly]
	What	- Site-specific and activity-related risks they are exposed to and safey measures to adopt - Workspaces visualization - Labor crew , safety, equipment, hazard and safety spaces
Emergency management training	When [milestone schedule]	Before each site layout transformation [layout switch]
	What	- Type 1: Workers' illness or accident - Type 2: Fire Management - Emergency procedures and equipment position (estinguisher - Escape routes and emergency assemply area - Rescue vehicles access and circulation paths

Figure 2: VR Training typologies

In the following Tables 3-4 a proposal of informative and graphical contents that make up the VR traing scenarios are explanined. Table 3 is referred to the BIM content which is the imput of the VR scenario implementation and Table 4 the addictional contents included in a VR application.

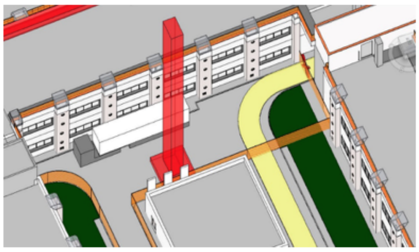
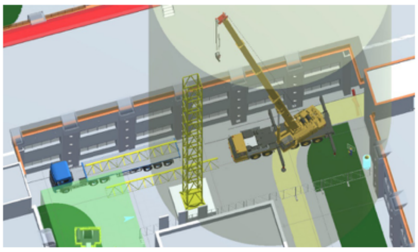
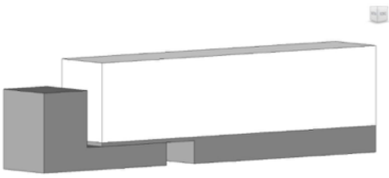
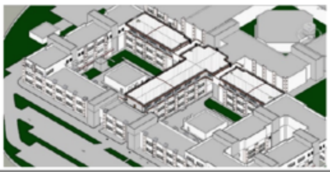
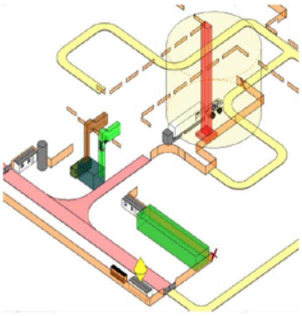
Site layout representation and visualization	
BIM Model	VR Model
	
The 3D geometrical representation and relevant data of the building and its environment. For each phase or site layout, it serves as 3D base static environment with all the information related for the VR scenario.	Site facilities, machineries, workers and any other site objects is replaces in the VR environment to reach a sufficient realism for a VR immersive experience.
Site objects representation and visualization (e.g. vehicles)	
BIM Model	VR Model
	
- schematic representation optimized for the communication of the relevant informative content during the layout design phase (vehicle dimensions, position, type, time, cost, etc.) - low LOD to keep a "light" workflow and not to affect model performance	- very high LOD of the 3D model to reach the higher grade of realism possible without affecting reproduction performances of the target VR device. (for a smooth VR experience mobile VR needs 3D models with a lower LOD than room-scale pc-based VR)

Table 1: VR Training scenario contents exported from the BIM environment

Content	Description
Building and Environment 3D model and data 	The 3D geometrical representation and relevant data of the building and its environment. For each phase or site layout, it serves as 3D base static environment with all the information related for the VR scenario.
Site layouts' 3D model and data 	The 3D geometrical representation and relevant data of site layouts and construction activities in the different phases. It serves as reference for the site implementation in VR. It includes: - Signs or symbolic virtual representation of vehicular and emergency site circulation; - Signs or symbolic virtual representation of storage, work and hazard spaces; - Machinery and equipment (depending on their LOD, they could be replaced with non-BIM 3D objects with enhanced graphical detail for VR realism purposes) - Site fences and barriers

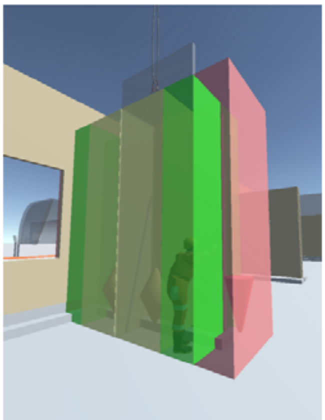
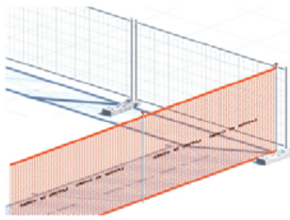
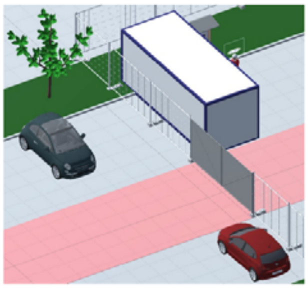
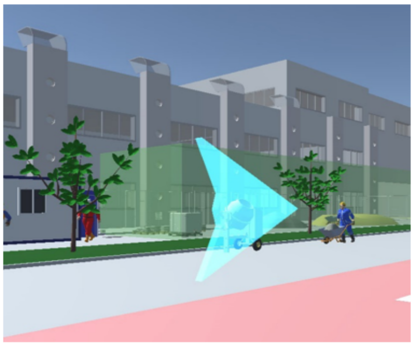
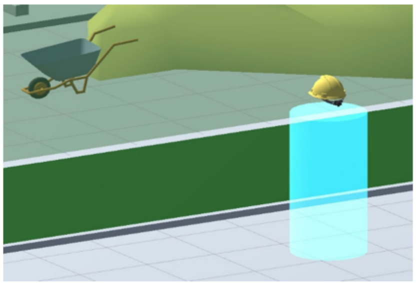
Content	Description
Work spaces 	In the VR scenarios with the simulation of the assembly of certain building component (a panel of a wood structure in the figure), additional virtual volumes and placeholders are positioned in the VR environment for the representation of the work spaces as follow: - Labor crew space (green): the space most likely occupied by workers during the construction activity; - Safety space (yellow): the space that has to remain free during the construction activity for safety reasons and that is occasionally needed to the workers involved; - Equipment space (grey): the space occupied by the equipment needed for the contruction activity; - Hazard space (red): the space with a specific risk related to the construction activity both for the workers directly involved and the possible other workers in the nearby; - Safety (yellow) and hazard (red) spaces symbolic placeholder: used to better spot the presence of a safety and hazard space.
Site workers 	In the BIM model, for each phase and site layout, workers are represented via symbolic placeholders to consider their position during the construction activities. Although this method allows to put the relevant health and safety information without affecting file performance and keeping the workflow "light" on the BIM side, the workers placeholders must be replaced in the VR developing environment with 3D objects with enhanced graphical detail for realism purposes. For this reason, every worker in the VR scenario should be represented in a static or animated way that reproduce the activities in which they are involved. Furthermore, all the VR scenario should be filled in with the actual workforce present in site and with other people outside if they are relevant for the training experience. (e.g. sites in urban contexts, activities carried out in partially operative buildings, etc.)

Table 2: VR Training scenario contents exported from the BIM environment
Table 3: VR Training scenario contents added in an VR application

Site machineries 	In the BIM model site machinery is represented in its operative position and with a virtual volume of its working space. Usually the BIM objects that stand for them have a rather low LOD and should be replaced in the VR developing environment with 3D objects with enhanced graphical detail for realism purposes. The replacement must keep the relevant health and safety information from the BIM environment and never lead to a misrepresentation in the position, type, dimension, working space and operational procedures.
Site facilities 	In the BIM model for each layout and construction phase, site facilities are usually represented in their current position along with storage spaces and other auxiliary elements. Not always these facilities have a 3D representation, and even in that cases they have a rather low LOD. For this reason they should be replaced in the VR developing environment with 3D objects with enhanced graphical detail for realism purposes. Each element replaced or added (e.g. building materials stocked in storage spaces) must be coherent with the site layout modelled in the BIM environment.
Fences and barriers 	In the BIM model for each layout and construction phase, fences and barriers are usually represented in their current position with symbolic 3D objects or even just with lines in 2D views. For realism purposes, dedicated 3D objects with enhanced graphical detail should be replaced or added in the VR developing environment in their expected position.

Context element 	Elements that help users to understand the environment they are in, during the VR training experience and make the scenario more convincing. Depending on the particular project and site they can be considered as contexts element: trees and vegetation, cars, street furniture, etc. Except for models used for presentation purposes (renders, etc) or other specific uses, these kind of contents are often not included in a BIM workflow. Nevertheless they are very important to increase the sense of immersion of the VR experience and therefore the effectiveness of the training.
Emergency vehicles 	With the aim to train site workers to the emergency management in case of fire and accident is crucial to add in the VR developing environment convincing 3D static or animated 3D objects of emergency vehicles in the position expected during the rescue operations in line with the site vehicular circulation modelled in the BIM environment.
Placeholders 	In the BIM model particular hazard spaces or areas for which is important to have specific safety information have been marked with 3D symbolic placeholders. In the VR developing environment some animation and interaction features are added to these completely virtual elements to better gain the attention of the worker during the training experience.

<table>
<tr>
<td>Virtual auxiliary elements

</td>
<td>In addition to the real virtual elements added or replaced with reference to the BIM model of the building site, there are other virtual auxiliary elements that must be added in the VR developing environment during the design of the training experience.

These elements must be designed to help the user to understand what-to-do and where-to-go during the experience and must be clearly visible and distinguished from the representation of the elements of the real environment.

As an example, with reference to the work done for this case study, among them can be included:
- Floating animated blue directional arrows (lead to the point of interest in the scenario)
- Floating bouncing red arrows (mark point of teleport from different levels of the site; used in case of the presence of a real elevator, stair, ladder or as a shortcut to rapidly visit different parts of the site)
- Gates (cylindrical volumes used as hotspot or triggers for interaction with the user; when the user enters the hotspot the construction phase changes along with the site layout)</td>
</tr>
</table>

Furthermore there are additional contentets that authors propsed to implement in the VR scenarios that serves for realism and immersiveness purposes:

- Audio contents: sounds from the site environment and related to the simulated activities; audio explanation of work procedure and other experience support instructions.
- Interaction: scripting of the interaction between the trainee and the site objects (machines, tools, materials, etc.) or with other virtual objects (see Table 4).

DISCUSSION

The proposed model will be tested by the authors in two different italian case studies in order to be validated. In terms of "VR developing technologies" -that were not the objects of such a contribution, the authors refer to cross-platform game engines dedicated to the creation of multimedia interactive digital contents deliverable for many different platforms from PC to mobile devices. Mainly designed for the game development, this engines are broadly adopted also to create interactive virtual reality environments with the combination of 3D models and other multimedia contents from every compatible source. The customization possibilities offered through code scripting have spread the adoption of this engines also far from the entertainment industry and they are more often used for research purposes and complex simulations.
Nowadays, unlike many industry and educational sectors where these engines are used to develop custom VR training experiences, in the AEC industry they are often relegated to project validation sessions. Without prejudice to the importance of the validation purposes for wich already exist commercial user-friendly VR platform, in the authors opinion the adoption of these engines is essential to develop the needed training contents in terms of realism and interactivity.

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17

Framework Agreement and Collaborative Procurement in Italian Legislation Enhancing a BIM Approach

KEYWORDS: Collaboration, Multiparty, Relational Contracts, Legal BIM, Alliance.

The research proposes an overview of the importation of a Relational Project Delivery Agreements (RPDAs) procurement in Italian legislation and the related issues. The AEC sector fragmentation, caused by an increase of building complexity and a change in the industry structure, is demanding a collaborative approach to the project to allow the possibility of a holistic vision based on a BIM approach. This work provides an overview of RPDAs applications on different contexts, highlighting benefits and issues related, including litigation resolution processes. A special focus has been kept on Italian context, where the stagnant construction market needs to be revolutionized, and better interactions among stakeholders are required. The research imports and adapts a collaborative procurement model, FAC-1 (Framework Alliance Contract), on Italian framework, tailoring the most important features of the model to the Italian legislation. The goal of this work is providing a methodology to validate a standard form of contract, aiming at an added value to construction sector and at applying them to framework agreements. Further developments consist in guidelines for contract management and evaluation of the project behaviour during different phases of the process.

INTRODUCTION

This research proposes an analysis of the fragmentation of the construction sector, due to the contractual tradition, that obliges the different parties to act in pursuit of their own interests, producing an escalation in re-work and in lack of process optimizations performances, as well as collaboration with the supply chain (Akyuz, Gursoy, and Celebi 2014).
In most Countries, construction projects are carried out by means of standard contracts, this procedure is new on the Italian scene, still used to building custom contracts (McKinsey Global Institute 2017).
In order to optimize the entire process, an analysis on the worldwide different types of contracts and their implications for the construction process was carried out. In this sense, the study of the state of the art of collaborative contracts, Relational Project Delivery Agreements (RPDAs), has highlighted their wider potential impact on the sector. In order to import and adapt a collaborative procurement model in Italian legislation, a collaboration has been developed among some Italian universities (University of Milan, Politecnico di Milano and University of Brescia) and Prof. David Mosey of Kings College London. This alliance framework, considering the actual Italian procurement law, defines a new standard contract able to create collaborative interactions.

The collaborative potential of contracts could be enhanced if several projects with common features were implemented within the same agreement, such as FAC-1. The article 54 of Italian Legislative Decree 50/2016 foresees a two-stage procedure, defined as “framework agreement”: in the first phase the framework agreement is concluded with one or more economic operators on the basis of one or more conditions governing the performance of works, services or supplies, which will be performed following the award of individual contracts; during the second phase, the "call-off contracts" are awarded with or without reopening the competition between the winners of the framework agreement . This research highlights the benefit of collaborative procurement model applied to frameworks agreements that could amplify the potentiality and benefits of collaborative contracts for at least two reasons. First, the biphasic nature lends itself to separating the pre-construction phase (first phase or conclusion of the framework agreement) from the phase in which the construction contract is awarded (the awarding phase through call-off contracts). The aggregation of different works within a single framework agreement makes it possible to maximise the exchange/sharing of information among the client(s) and the successful tenderer(s) of the agreement. As a result, the contracting authority is not in a situation of 'tied negotiation' of a bilateral nature, as envisaged by Mosey (Mosey 2009), but it makes room for competition. Secondly, the adoption of a framework agreement makes it possible to create the conditions for repeated interaction between one or more contracting authorities and all the successful tenderers, a condition which is essential in order to be able to manage the relational aspects of construction contracts (Mosey 2009).

COLLABORATIVE PROCUREMENTS IN A WORLDWIDE SCENARIO

Beside different contract approaches, there are different collaboration levels that could be set in a project (Lahdenperä 2012).
The contract could be seen just as a promissory agreement among people recognized by the law which sets the rules of interactions among the participants. According to Construction Leadership Council (CLC) (Construction Industry Council 2013) report on productivity, collaboration set at the contractual stage, provides the basis for the Lean principles of reducing reworking and optimizing processes.
The misalignment of design team’s goals and the site design work-flow goals create a waste, especially during the construction phase, resulting in time and budget overrun (Sacks, Radosavljevic, and Barak 2010). The lack of communication among team members’ produces (Tauriainen et al. 2016) misunderstanding resulting in sub-optimized buildings (e.g. re-work caused by unsolved spatial clashes during construction phase) (Sacks, Radosavljevic, and Barak 2010).
All these circumstances are emphasized when collaboration doesn’t involve all the participant to the project (Myerson 1999).
Over the recent decades, some traditional project delivery systems have emerged claiming to fill the gap between the design and construction projects, but they have shown to be not efficient enough (e.g. Design Build or Construction Management at Risk) even if they are generally used. Most of the time, people try to plan collaboration just modifying traditional contract standard.
Therefore, collaboration has completely different structure. In this context, collaborative contracts standard (e.g. AIA C191, PPC2000, FAC-1, NEC4, JTC) were developed in many countries, but they mainly have the same characteristics, which can be summarize in the following: (i) multi-party, (ii) Early Involvement of Key Participants, (iii) team goal validation, (iv) shared risks and rewarding and (v)

collaborative decision making (Di Giuda and Villa 2016).
In the global panorama, two main approaches have been developed: (i) the first consists in the American approach, called Integrated Project Delivery (IPD), where the same contract groups the different participants in the process, entrusting in a single contract all the phases of the project; (ii) the second, on the contrary, typically European, is based on the union of several contracts previously awarded via an alliance framework, the main example of this approach is the FAC-1.

AMERICAN APPROACH TO COLLABORATION

In US, a new form of collaborative contracts is called Integrated Project Delivery (IPD) (Miller et al. 2014). It started as an alternative to the tradition Design-Bid-Built in order to reduce complex project risks, and imposed a mental shift in the fulfilling of the contract (Lichtig 2010).
Due to their structure and composition, traditional contracts unavoidably create a conflict of interest and they impose a rigid division of the stakeholders' works. The two main standard contracts developed in US, which can help people establish s real collaboration through a multi-party integrated project delivery agreement, are AIA C191 and ConsensusDocs 300 series. The integrated agreement creates a system of shared risks, with the aim of decreasing total risks of the entire project. IPD contracts aim at including most of the consultant and sub-contractors in the agreement.
A general rule is to have at least half of the construction costs discussed at the decision table (Lichtig 2010). There are two ways to add new subjects to the team: the first is through call-off contracts. This approach set the new member in the teamwork with the same duties of the other parties, but he do not share nor profit nor right to vote. The second is through a joining agreement, as a consequent amendment to the original version.
The American experience has demonstrated how the public administration prefers a joint entity before a contract is stipulated in which they entrust the design and/or build a project. Even though, according to the past application of IPD (e.g. Sutter Health, Cardinal Glennon Children's Hospital Expansion), this contract model provides many benefits in terms of cost and time control, in management of the supply chain and reducing the risk in comlpex project.
This approach is common in US, but it is still not seen as the solution to a collaborative approach. This is one of the main reasons why framework alliancing was created, to accommodate market needs through a transition instead of a paradigm shift.

EUROPEAN APPROACH TO COLLABORATION

In Europe, the collaborative approach is quite new in the AEC, beside the form of Design Built.
Even though, some European countries (e.g. UK) are applying these practice for quite a few years. A new standard of contract, PPC2000, has been created at the beginning of this century: used in the last few years, it has had a great usage in the private sector and it was also validated by many companies and by the UK government. This document is close to American conceptualization, as it is a contract which includes (i) the aggregation of the team, (ii) the entrusting of the project, (iii) the construction phase and (iv) the maintenance.
As shown in Figure 1, this contractual typology allows to join in a unique framework different call-off contracts, previously awarded, and mage all the interaction among them. Shared objectives, success measures, targets and incentives are the core of the framework alliance, especially in the FAC-1, which can take a multi-party or poli-party configuration according to a case-by-case evaluation, namely adding to the core group of the contract or all the representative of the parties, as in the first case, or all the representatives, as in the last case.
This collaborative agreement standard has been introduced in 2016 in the United Kingdom and has been used for many public and private projects, such as in the case of the Surrey County Council Trial Project, it was adopted over the year in over 12 B£ of procurements. The alliance has a joint aim, the realization of a project guarded by the governance structure of a core group. FAC-1 is the first standard contractual model in Europe able to accommodate all the characteristics of this methodology allowing a transition from traditional contracts to collaborative ones. At present, some States such as Brazil, Bulgaria and Germany are adapting this contractual form. FAC-1 is structured as a Common Law Contract; and for this reason, it's useful starting from the General Conditions, containing

the general rules, then moving on to the initial part. The entire document is related to the Definitions, which states the way to read correctly the standard contracts. Consequently, the General Conditions, referred in the Cooperation Agreement, are the contract column. One of the main features of the contract is that it could be bended to the requests of the collaboration members just selecting the clauses that they want to apply. FAC-1 has pre-structured Annexes and Modules in order to set the requests made or the action carried by the collaboration. Through an information preset included in each request, each party structures the request in order to provide all the needed information.

In this scenario, UK is the leading country that has applied and developed a RPDA for AEC industry. FAC-1, Framework Alliance Contract, is the first European contractual standard that is able to link more single set from a bi-lateral contracts in a multi-party agreement. This approach is applicable in different scenarios and its methodology fits with BIM methodology and with collaborative system (Di Giuda, Giana, and Villa 2017). The European Directive 2014/24 recognizes the joint planning as one of the methods for building public works, the core principle of that partnership is that the design quality would be superior if the project is developed jointly. The Laws realized on January 28, 2016, Legislative Decree 50/2016, no. 11, (Italian Parliament 2017) has drastically limited the use of integrated tender based on technical design. The reviewed Contracts Legislation has further restricted the joint design operation scope and execution contract to activities characterized by high technology or innovation elements that need the division of these phases. The value of a joint project development is superior when the project is produced by a collaboration instead of a sequential development, so a joint alliance adoption impacts on time and costs.

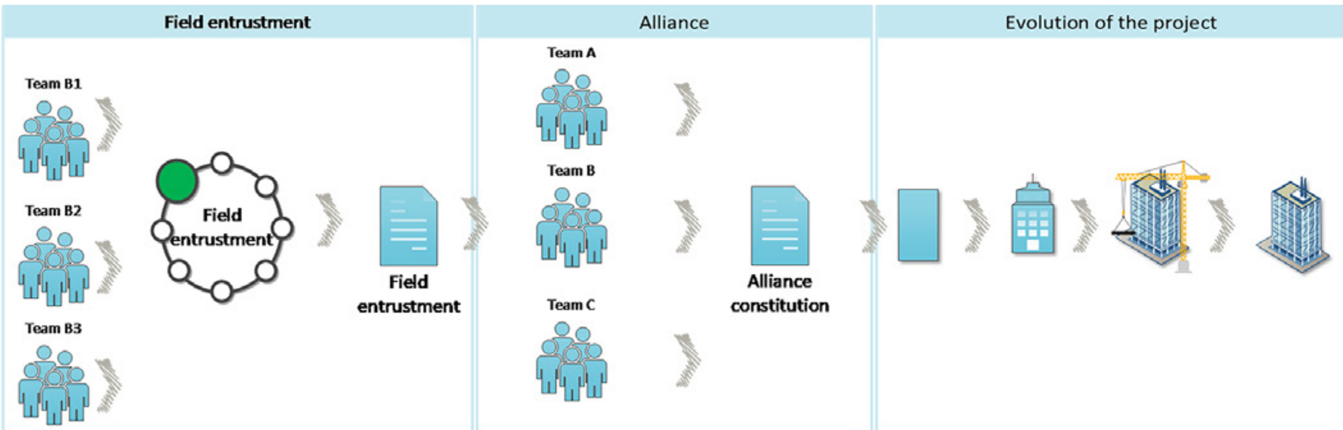


Figure 1:Alliance procurement process

METHODOLOGY

The evolution of BIM methodology is imposing also a shift from traditional contract, which segregates different stakeholders, to a collaborative one. In this context, the BIM helps control and implement the result of the contractual evolution form during the whole project evolution. This research provides an analysis of the importation of a collaborative agreement in Italian legislation enhancing a BIM approach. The adaptation of FAC-1 was conducted by the teamwork of three different universities, which considered the alliance framework the most suitable and flexible standard form of RPDAs contract. The analysis of the state of the art of collaborative procurement in a worldwide scenario, summarised in this article, provides a comparison of the most suitable contract for Italian legislation. Namely, the American approach, where the same contract aggregates different parties entrusting different phases of the project via the same agreement. This approach is not feasible to be applied both for public and private scenario due to the limitation of contract law. The UK approach, on the other side, is based on directive 2014/23/EU and 2014/24/EU and it allows the union of several contracts previously awarded in a framework through a procedure called alliancing, the main example of this approach is the FAC-1.

A multidisciplinary group of researchers understood the possibility to import FAC-1 into Italian legislation. The FAC-1 was conceived and drafted by Prof. David Mosey PhD, Director of the Centre for Construction Law and Dispute Resolution of King's College in London. This process is not a simple translation from a different language, but it involved a drastic modification of its content to fit a different legislative standard. The process was developed

by a collaboration among people with different background, who could exchange information and fully comprehend the implication of each single word, through a crosscutting analysis. This research will provide a project and program management tool to clients, who would like to manage complex situations.
To prove the importation legitimacy four levels of control analyses were put in practice. The first approach to the alliance framework imposed a deep understanding of the word included in the contract definitions. This first step imposed an iteration of translations to fit the meaning and the philosophy of the contract. When the entire contract was translated a first control, researcher conducted a first internal control.
An internal quality control of the contractual model was conducted both in term of immediate comprehensibility of the terminologies used in the translation and the consistency of the contractual model with the reference market (Italian end European). It required many adjustments in order to realign the contract philosophy to the Italian contractual code.

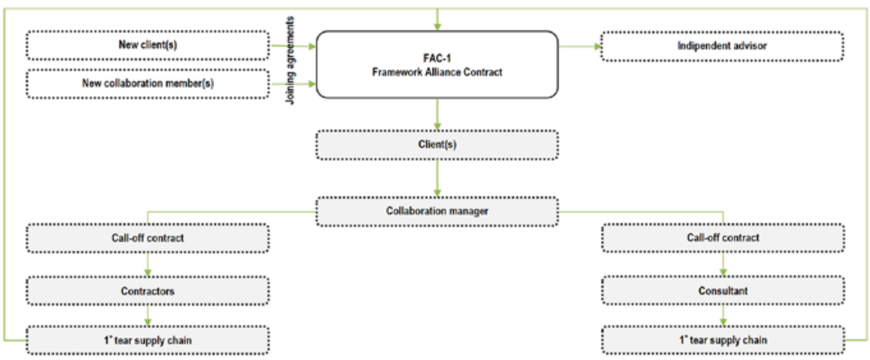
A second step consisted in the resolution of the problems previously individuated and in the validation through an expert. This process was developed in collaboration with Prof. David Mosey, who drafted the original agreement. He validated the agreement according to the theoretical flux of the contract. The comparison between the two versions occurred among the two team explaining the modification of the contract to fit the Italian legislation and through the explanation of the adjustments of the contract. The third step was conducted after the validation of the previous one. In this case, external experts reviewed the Italian form of the framework agreement.
Various institutional entities, local authorities, universities, trade associations, representatives of the administrative judiciary and private operators was consulted to analyze the contract. They provided some doubts and uncertainties, from different perspectives, which were analyzed and solved discrepancies. The multidisciplinary group embraced all the doubts and problems detected and re-finalize the contract standard. A second round of external controls was conducted providing the contract to the reviewers and all the comments were discussed during a round-table discussion.
All the people, invited to discuss during the previous step to submit comments to the contract standard, attended the discussion. During this event, a few points of the standard were discussed, explained and commented for the regulatory bodies sensitivity, the coherence with Italian legislation and the market requests. A last adjustment was brought into the contract.
The contributions received - further verified, also from the point of view of consistency with the original philosophy of the contractual model - were included in the final version of the document. The process, structured in such a way, allows, enriching the alliance contract by the experience of various leading players of the national panorama.

ADAPTATION OF FAC-1 ON ITALIAN LEGISLATION

The adaptation process of FAC-1 was developed by a collaboration among people with different background and adapted the standard to Italian legislation, modifying its content in a drastic way in order to fit a different legislative standard. This framework provides a project and program management tool to clients, who would like to manage complex projects. According to the analysis conducted by OICE (Association of Organizations of Engineering and Technical-Economic Consulting), BIM projects are drastically increasing their importance in Italian market and for this reason, the framework will provide to it a solid base on which BIM methodology can fit the client requests. The Italian FAC-1 establishes a system regulates legal relations among several subjects involved in the implementation of one or more projects, defined as Programs, by linking several contracts with a view to encouraging collaboration and coordination of the various activities. Through the stipulation of FAC-1, parties undertake to work in a collaborative spirit and to carry out activities, called "Alliance Activities" – added value, site organization efficiency, BIM use - consistent with the aims identified by the Customer, which may be public or private. The provisions contained in the General Conditions and Annexes may be departed from or modified in the FAC-1 which is composed of several Modules, specifying respectively:

- The Objectives (KPI), Success measures, Targets, Objectives and Bonuses (Schedule 1);
- The Timetable (Schedule 2);
- The Risk Register (Schedule 3);
- Awarding Procedures (Schedule 4);
- Contractual Models (Schedule 5);
- Legal requirements and special terms (Schedule 6);

FAC-1 is a contract that suits a general goal called Objectives, which will be accomplished by specific Objectives measured through Key Performance Indicator (KPI) (Jonsson and Rudberg 2017). The contract can pursuit both



the aim of a Project or a Program. The collaboration is set among the Client, the Alliance Manager and the Collaboration Members who sign the FAC-1.
The standard flexibility allows including more members to the collaboration both as a New Client and as a New Collaboration Member. To pursue Collaboration, a series of activities have to be completed and each member can propose a series of activities to the Client in order to optimize the project, their payment is at the discretion of the Alliance Manager and the Client. Sometimes the added value that gather from a new activity repay the effort extended in the action. Whether FAC-1 intervenes in a Program already in the design or execution phase, or where FAC-1 precedes the start of any activity related to a Program, the Collaboration Members are required to present their Collaboration Proposals, which may be limited to simple participation in meetings, drafting reports or sharing relevant information with other Collaboration Members, or they may consist in the provision of specific services. The Collaboration Activities execution takes place - according to the schedule in part two - on the basis of Requests formulated by the Client, indicating the contents to be implemented, the execution terms and the amount due for them, calculated on the basis of the Collaboration Price. Payment for Collaboration Activities shall be made in accordance with the conditions set out in FAC-1, a specific payment policy states the workflow of the procedure to trace all the payment among all the parties and to set the fee for delays. The Alliance Manager in relation to the Purposes of Collaboration monitors the performances and the Objectives, based on Members' activities, are assessed by shared KPI. The profit sharing is one of the key of contracts based on collaborative procurements. For instance, the partaking of the supply chain can optimize the process and produce a huge reduction of the costs, thanks to shared procedures.

THEORETICAL APPLICATION OF FAC-1

In order to demonstrate FAC-1 flexibility, two examples of its application are presented, both on side of public and private investors. Starting with an example from the public sector, we can imagine being in a situation where three municipalities with their street lighting companies decide to optimize the service offered to their citizens by creating a single management system for the three municipalities.
This alliance can provide a facility management system, shared among them, to provide a major reliability due to its development supported by experts. Thanks to the framework, parties can be joined in the contractual scheme by establishing a dialogue aimed at a single goal dictated by the Client. Single installation companies can participate by offering, for example, an implementation of their System's performance. This can be achieved by sharing supply chain information, for example, using the same supplier. In this sense, supplier optimization could generate a better result. At the same time, the various companies being companies in the sector can help the maintenance manager to choose ways that are more appropriate by improving the Final Service. Clients can choose which of the improvement proposals to adopt, and accept it only if the proposal improves the final result. The final result is obtained via a cooperative approach. For example, in this case, the maintenance platform will fit the requests and the standard procedure of the client. This collaboration can optimize the cost of the service, imagining that the maintenance procedure is close to the standard procedure.
If we deal in the context of the private client, the general contractor of a work, decides to establish a collaboration agreement with the other participants in order to optimize the process in terms of (i) certainty of outcome, (ii) integration between design and construction and finally (iii) safety. In this hypothetical scenario, for example, the designer could offer as an additional service, even

Figure 2:FAC-1 interactions among members

payed, the implementation through BIM methodology so to reduce the design errors and clashes, increasing the reliability of the process. In this sense the client could accept an extra cost in face of fewer problems during the construction phase in regard to a final saving due to a certainty of the result. In this scenario, others parties can promote different proposals, such as energy improvements for the reduction of the cost of management or changes to the schedule for the optimization of the workflows. The collaboration sets not only a legal agreement, but it aims at improving the quality of the project. It is the reason, why collaboration has the ability to improve the quality of the project and improve the exchange of information.

The client, who set the framework does not need to be the owner of the construction, but he could be a person or a firm that want to set a collaboration to improve the project. This approach could put also the design firm as employer in the collaboration process to show its flexibility of application.

CONCLUSION AND FURTHER DEVELOPMENT

The research investigated different contractual typology in a worldwide scenario, among them researchers individuated the one closest to Italian legislation. This approach provided a solid base to adapt it in Italian legislation. FAC-1 is a flexible meta-contractual model, in which parties are given the opportunity to consider efficiencies in the supply chain that make the flow of information more transparent and reduce the overall cost of performance. The Client could use the standard in order to create a collaboration, legally valid, among their sub-consultants and/or sub-contractors. The higher level of transparency and increased responsibility, towards both the Client and other Collaboration Components, required by each private operator in the pursuit of collaboration, are counterbalanced by the economic compensation provided. FAC-1 is a contract that regulates and manages the inter-relations among different contracts and, namely, the relation among parties, which are not directly associated over a contract. In addition, FAC-1 is intended to build a solid legal framework for the BIM use in the construction sector, through the following means of developing a positive interaction among different design teams and linking the various phases of construction of a work (Alwash, Love, and Olatunji 2017). FAC-1 approach invites the participants to submit their Collaboration Proposals and enhances the professional expertise, thereby exploiting economies of scale and achieving cash or other benefits.

This meta-contractual form permits to increase the coordination of different subjects' activities with greater guarantees of results and with a reduction of unexpected interference, possible over-budget and overrun of time. Especially in complex project, this approach allows an efficient management with multiple subjects' contributions. Collaboration, in such a way, providesan added value in terms of work or service sustainability, site organization and working conditions efficiency, collaboration with the supply chain, reducing re-work. The early involvement of all professionals allows to prevent and/or reduce the mistakes, which must be reported to Alliance Manager that improves project final quality. The alliance members promote transparency in relation to the specific aims and objectives of collaboration. The intensive exchange of information enhanced by the meta-contract provide a risks prevention and management during execution, because problems are shown to all parties. In conclusion, this approach leads to a reduction of the litigation by preventing and extra-judicially handling possible claims. This contract provides the ability of team members to rely on the exchanges of BIM data and setting among different call-off contract the same rule in order to provide data consistently among parties.

At this point, the research provides an approach to the problem of the SMEs of the sector, in fact the collaboration that RPDA established among stakeholders is difficult to achieve and, most of the time, it is unattainable in a traditional process, although the promised success (Ghassemi and Becerik-Gerber 2011). The new contract improves the processes management decreasing the public administration burden often due to litigations caused by traditional contractual procedures. The research will produce guideline for the contract application both for private and public users to integrate smoothly collaboration in work procedures. The "Adda Martesana" Municipality is applying this contractual model as part of the project to build a middle school in Liscate (Italy) as first case of framework alliancing in Italy.

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18

A Theoretical Framework to Align Lean Construction Techniques in the 4.0 Building Industry

KEYWORDS: Building Process Management, Lean Construction, 4.0 Industry, BIM, Agent-Based Modeling

The big challenge of the current industrialized society is the concrete adoption of 4.0 paradigm: this consists in the interconnection of the physical object to digital computation, by a collaborative and dynamic approach (i.e. Internet of Things – IoT). The creation of this interconnected computational network allows verifying the efficiency of a production system by recursive checks, which locates lacks and misproductions into the production chain. The progressive improvement of production quality, intended as the approach of needs and performances, is the core of Lean paradigm. In the big picture, these are the fundamental elements needed in the current condition of the Building process, that has an evident delay in technology and management techniques adoption. As an answer to this need, the research is oriented towards the definition of appropriate methodologies useful to seize the opportunities that the paradigm of 4.0 industry offers to the building sector in a lean way: the goal is, on the basis of literature review and tests on techniques and tool currently used, to outline a methodology that, using the continuous exchange among physical devices, data-processing centres and vice versa, can give new spaces of application to Lean methodologies in the construction sector. Considering the complexity of the Construction Process, even for small and medium projects, it is necessary to design on collaborative digital platforms, such as Building Information Modeling - BIM: in this research, the BIM model is the starting point by means of a quite-reliable database of properties and geometries of the building. On the other hand, all the problems related to the 'BIM Utopia' are investigated, such as the limits of interoperability, the slow adaptation of the construction chain to the procedures of good practice and the use of digital tools, as well as market fragmentation, which is very marked in culturally 'handcrafted' contexts, such as the Italian one. This research describes, basing on the test conducted on the existing methodologies, a theoretical framework to align Lean Construction techniques in the 4.0 building industry. The results show how is important, to reach the goal of optimization – the core-mission of Lean and 4.0 – move beyond BIM, in the direction of implementing existent methodologies and tools with Artificial Intelligence techniques, like Agent-based simulation. In the proposed framework, this is possible thanks to the improving of BIM capabilities with Autonomous Agents. They are modeled according to BIM object feature but including also relational rules and goals. So, after the definition of needs and requirements of design and construction process they tend, after ever modification occurred in the design environment, to create a new state of balance, defined by reciprocal satisfaction of boundary conditions: in summary, the Agents simulation allow to define, after every project modification, the satisficing balance condition respecting to all constraint that characterizes the project. This could properly support the designers in problem-solving, manage the huge mass of data that characterize the building industry and preserve the quality of the architectural design.

INTRODUCTION

This research focuses on the investigation of the new possibilities given by the development of Information and Communication Technologies - ICT to manage Building processes, with the ambition of grasping which vision is more appropriate to the spirit of our time.
In this field is clear that innovations in the ICT sector should not be seen as a parallel path with respect to the social and cultural debate related to architecture, but it is necessary that the different instances influence each other, as happened for the study of lights in the masterpieces of Caravaggio, the perspective in those of Piero della Francesca or in the implementation of digital tools of geometric modeling implemented by Gehry (Pascual, 1998).
It is therefore clear that, in addition to the increase of the performances of technological tools, it is necessary to adapt tools, methodologies, knowledge and the vision of a sector that, otherwise, risks losing the opportunity that the galloping development of the digital world offers; otherwise, the same development requires a constant updating of the results achieved, thus avoiding the risk of losing dominant positions and become, in a short time, obsolete compared to the needs of the industrial sector.
Hence, the target is in linking the information model of the digital building (in terms of Information Modeling) into an environment-mirror modelled by autonomous intelligent entities (Autonomous Agent). The prediction produced by these real construction process, in virtual-digital environment could, furthermore, be improved with the connection with new tools that, concretely, defines new paradigm in construction sector. These are the encompassed in 4.0 industry, in terms of connecting human resources with machines, also in terms of improving the data-exchange among actors (i. e. mixed reality devices for sharing knowledge directly on site, or wearable technology provided by RFID to warn workers about risky areas or activity etc.) In other words, the improvement of tool opens the way to a better human-machine interaction, capable to grow up the productivity and the global quality of building design in our digital era that, in reality, allow to extend the industrial concept of mass customization also in construction that, traditionally, is heavy conditioned by traditional approaches.

BACKGROUND: THE BROADENING OF INNOVATIVE HORIZONS

From the very beginning, the Building Process actors have found in Computer Science a valid partner, able to effectively manage important amounts of data and equip, in an ever more democratic way, the Construction Process actors with tools that are sufficiently complex, with respect to the insidious complexity of the design problem (Kunz & Rittel, 1970). These tools have gradually evolved, depending on the available computing power, allowing at first the possibility to manage geometries and data in separate environments and, from the last decades, modeling information and knowledge in interconnected holistic environments, such as happens in the BIM approach.
In most of industrial sectors, the opportunities provided by the digital revolution have been applied from the outset, with all the limitations and problems linked to the immaturity of these systems.
If we consider that we are still in the pioneering phase of the digital revolution, we can say that the results have been, at least, encouraging.
Differently, the Construction Sector suffers of a traditional reluctance towards innovation: the design procedures of wide use, in fact, still show several shortcomings, such as the low use of Information Modeling or (so?) the fragmentation of knowledge, continuing to work according to the logic of 'watertight compartments' consisting of design teams that, each for its own competence, store their methods and results in 'mental silos' (Clausing, 1994). Thus, the project is divided in specialized phases, to be verified in a consequential-linear way: this implies the presence of many parallel partial and sectorial projects, verified only within their own knowledge domain.
So, their contents and concepts are not integrated with each other, despite the complete use of advanced tools based on Computer Aided Architectural Design - CAAD. Therefore, despite the well-known potential of CAAD system in realizing a collaborative design approach, these are not adequately used in an integrated design vision (Carrara et Fioravanti, 2001), supported by digital networks: the problem, hence, is not totally connected with tools or the related digital environment, but in the need of a new approach, based on the new view about Building Process Management in a digital/collaborative way.
In this sense, the construction sector cannot miss the opportunity given by the paradigm of industry 4.0 in improving the connectivity of objects among themselves and between operators: thanks to the Internet of things, it is possible to increase the use of sensors in the operational phase of the building, to analyse the evolution of the needs and preferences of users; then, in the construction phases, it can connect the physicality of building site to the digital environment, necessary to control the quality of materials, construction and installation of systems and the overall performance intended as the achievement of the objectives set in the planning phase.
Other interesting perspectives openings towards the Facility Management, were the cybernetic connection among building object and management tools, allow to verify the operational response that the solutions designed give to the needs of users, and all the necessary materials and interventions needed from the building during following years.
In this reciprocal exchange of data and knowledge, human intelligence is flanked by Artificial Intelligence to better express, thanks to the possibility of having predictive tools with respect to the choices made, a strategic vision for process management.
In the building construction process - dominated by uncertainty - these possibilities open up unprecedented scenarios, with regard to the possibility of efficiently optimize Building Processes in terms of design support systems improvement, the reduction of effective time and cost of construction, a reliable forecasting in the maintenance and management of the real estate assets.

INTRODUCING LEAN VISION IN THE DIGITALISATION OF A/E/C SECTOR

The management techniques of complex project have now been extensively tested and catalogued, according to various categories - both operational and logical - that have been consolidated for years. Starting from the rationalist-scientist position of the late nineteenth century, first formalized by Rankine (Koskela et al, 2017) and then refined and propagated by the Taylorist school, the typical reasoning of engineering was framed according to the deductive method (from postulate to theorem). This is particularly evident in purely-analytical approaches: given the characteristics of an element and established the relative boundary conditions, the prevailing behaviours arise.
On the other hand, the inductive approach is based on the critical observation of the real world, in order to extrapolate its empirical knowledge, and then formalize it in rules of good practice; from here it is possible to conceptually 'induce', adapting the knowledge base acquired to the specific case. These adaptation processes, guided by the technician's experience and his ability to address a strategic vision to the solution of the problem, therefore allow to reach the satisficing state (Simon and Simon, 1962) with respect to the results to be achieved.
In the Building Process Management these two approaches have been declined according to the methodologies push and pull: the first one, is based on the push of production chain on the

basis of the starting conditions; the second one instead, is pulled according to the conditions and the adjustments needed at each time, basing itself therefore on the observation of the real world and on the forecast of how the process can be adapted to the dynamic project/building conditions.

In the peculiarity of the construction sector, the management of push-based production was applied through the Critical Path Method - CPM in the 1960s, with a clearly rationalist imprint (Koskela et al. 2014). In applying this method, the reference to be followed is only the ideal conditions assumed for the production line, leaving the minimum space for the complex variables given by the real world which, instead, in such a dynamic context as the construction site, become decisive for obtaining the result.

In searching of optimisation methods for the construction sector, the application of techniques developed in the field of vehicle manufacturing (i.e. the lean manufacturing approach), has been a long way forward. This consists in optimizing the use of available resources in a process, minimizing wasted time, under-utilisation of work areas and resources and, in a broader sense, misproductions. These are the inefficiencies that, in fact, bring useless costs and inefficiencies so that each project systematically becomes a race to the unknown.

Therefore, the necessary integrated approach to project management allows not only a change in the operating and management methods of an architectural implementation process, but also a different cognitive approach capable of bringing the competences of the actors closer with the aim of reaching a satisfactory condition, with respect to the project requirements, and arrive at the best possible solution in a shared way (Froese, 2010).

In this context, it is necessary to provide to process actors 'aggregators' capable of always keeping the project variables in connection and, therefore, the creation of a digital knowledge formalized in an explicit way, cataloguing elements used in previous processes and, above all, their relationships. This condition, in these years, seems more and more within reach (fig. 1).

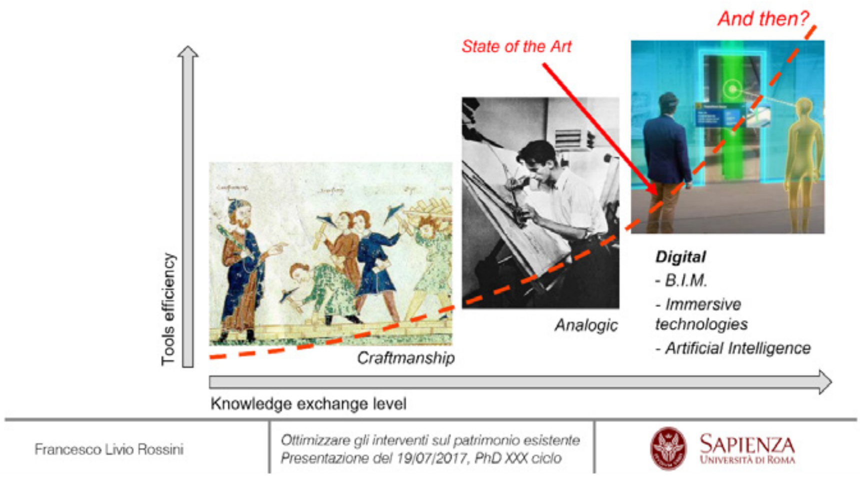

Figure 1: evolution of production efficiency in Building Design Process

DIGITAL TRANSITIONS IN BUILDING CONSTRUCTION MANAGEMENT: A DIFFICULT PATH

Unlike the first wave of CAAD, where the lower diffusion of tools and data-networks overshadowed the problem of design collaboration, in the second phase, between the 80's and 90's, the widespread presence of digital tools and the progressive construction of the necessary digital infrastructure, determined the possibility to finally share collaborative platforms and increase the quality of work through continuous and reciprocal exchange of knowledge, although not fully formalized.
Now, in the middle of the third wave, characterized instead by the adoption of highly effective technologies in the exact definition of a building component and objects in general such as Building Information Modeling - BIM and by interoperability platforms such as the Industry Foundation Classes - IFC, the digital construction of the project is achieved (Fischer et Kunz, 2004). In this direction, research lines about interoperability are achieving important results, as described by Daniotti et al. (2017) in defining digital platform of interoperability. But, according to Miettinen and Paavola (2014) the BIM is still an 'utopia', a promising technology that have to be still implemented to manage properly the complexity of the Building Process.
Therefore, the challenge consists in going beyond the current potential through collaboration, understood as the management of the flow of information and knowledge between the actors, aiming at the mutual increase in governing design problems, and the possibility to interact with simulative models, capable of foreshadowing the realization and the behaviour of the project.
The advantage is therefore in being able to verify in advance both the design solutions and the construction possibilities, in a continuous evolution of the digital project.
In this way, thanks to the advances in digital simulation, with which it is possible to define choices and their consequences, it is possible to optimize the use of resources involved (i.e. workers, spaces, materials etc.) reducing the typical risks of construction like variations in progress, with the known repercussions both in terms of time and cost, both on the overall quality of the process of construction of the architecture (fig. 2)

Figure 2: example of propagation of Project Construction cost and time and the related incoherency between the final result (on the left) and the initial project. Rome Convention Center.

METHODOLOGY: IMPLEMENTATION OF BIM WITH AGENT-BASED SIMULATION

In the current literature is extensively documented how the digitalization of Building Process could bring benefits in terms of optimization of resources involved in the Construction sector. On the other hand, the limits of the most promising methodology in this field - the BIM - , are well known: interoperability, generation gap, digital divide etc. Now, the interest of the research debate about design methodologies is moving from digitalization of process to the spreading of computational into the real life through IoT, AR/VR/MR etc.
So, digital model of building has to be interconnected with the physical environment with devices that, for instance, are installed in site to gather data like occupancy, progression of works, prevalent behaviour of workers (or occupant in case of evaluation studies of usability of buildings) and so on. Furthermore, designers have the need to manage a very complex amount of data, that requires the evolution of this tools from a reactive behaviour to the proactive one (Fioravanti et al., 2017).
This means that a modeling tool does not merely act basing on designer instructions but providing him in advance choices that have a high probability to be the more satisficing to the project needs. To reach this achievement an Agent-based simulation model that integrates BIM capability is proposed: in summary, this simulation environment sense the needs and the resources modelled into the BIM environment and, via recursive simulation, predict the best use of design object available in the model in respect of the needs to be satisfied.
These agents are characterized by a set of rules to be respected, related goals to be achieved and, in relation to these, set mutual relationship that defines the way in which, by applying their inner systems of rules, Agents modifies their internal balance. This process happen hundreds of times till the definition the best way to pass from the starting condition (Contest at time-0) to the defined next step (Contest time-1). If the simulation take place into the BIM model, sensor and actuator of agents act into values of digital model, if the agents are connected to the real environment – e.g. Facility Management, Digital Fabrication etc. – sensors are physically connected to the real environment, then actuator (i.e. mechanical systems) after computational inference, modifies real object, materialising the digital continuum that is the core of 4.0 (fig. 3).

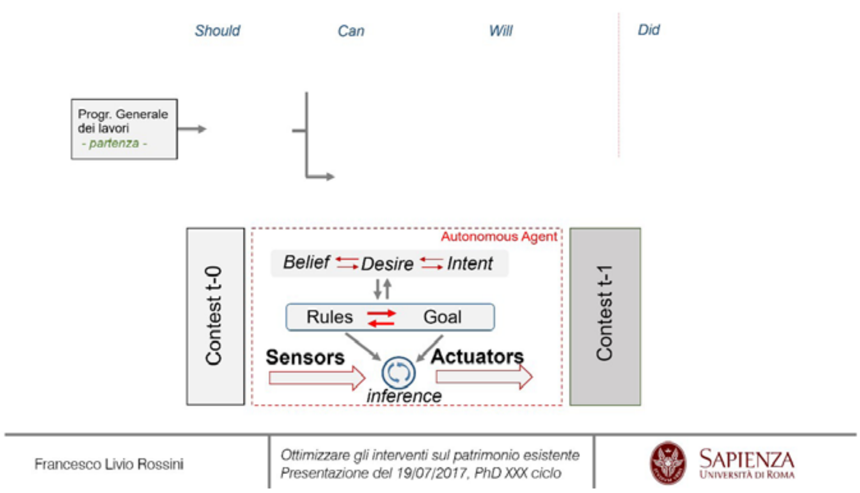

Figure 3: the inner conceptual structure of Autonomous Agent.

Agents are autonomous: autonomy, in fact, means the ability of an agent to act, after perceiving a stimulus, by applying rules aimed at achieving an objective without direct human control. This autonomy can be declined according to different levels of complexity. In fact, an Agent can have very simple behaviours, purely reactive with respect to the application of conditional rules of the if-then type, towards more complex realities such as the Belief-Desire-Intent-BDI architecture. In this case: the Belief is generally defined as the information that an agent has with respect to his environment, which can be more or less accurate, depending on the type and precision of the sensor used; the Desire instead describes one or more objectives that an agent would like to see concluded, with the definition of priority rankings; the Intent is the way in which Agent tries to intervene on the current state, both within his system and in the environment in which he is immersed.
Agents in this case represent the elements edited in the model, and the external components that influence these building elements; these are the context, understood as the organization of the
construction site resulting from the iterative feasibility checks and the resources to be employed, defined in turn according to the tasks and the degree of productivity that they can achieve.
In this way, the Lean approach is applied in the way in which this intelligent digital system is able to optimize the resources involved in processes. This became possible when the system is:

- **able to optimize the project** in terms of reduction of hard/ soft clashes, the possibility of project-inconsistencies, and related reworking activities, and/ or reducing the redundant solution (mostly in HVAC design) and, finally, improving the usability of architectural spaces by users in operational phase;
- **able to optimize the construction management**, in terms of a better management of working area through the use of Line of Balance – LOB Project management approach, in a construction site planned with the Location-based Systems – LBS (Rossini et al, 2016);
- **able to minimize** the interruption of building use, warranting the service provided by the building, thanks to the reliable definition of time and space occupation given by digital simulation of construction and construction site development during the whole cycle of works.

CONCLUSIONS AND DISCUSSION

This research is included in a broader project, that has the goal to formalize a design digital environment for the co-creation between humans and machines. In this way, it becomes easier and more reliable to make, in earlier project phases, accurate assessments of the feasibility of projects, with the goal to save resources and safeguard the – often weakened – design quality.
Considering the aspects related to Agent modelling, we have not yet structured knowledge bases or 'well-defined' knowledge structures, based on scientific observation of performances of construction sector, or extracted from large databases: therefore, especially in the definition of the productivity of the operating teams, one must still rely on the implicit knowledge of the actors involved, the Expert.
The opinion of the Expert is therefore altered by the influence of (his) bias or evaluations that are simply based on performance that cannot be objectively verified.
Although such a simulative system could prefigure scenarios that are certainly valid from a logic/informatics point of view, they are based on a subjective knowledge base, which is therefore characterized more by the implicit knowledge of the Expert than by the objective observation of the phenomenon. In further researches, the focus will be targeted on the data gathering in the construction process, using advanced techniques like Big Data.

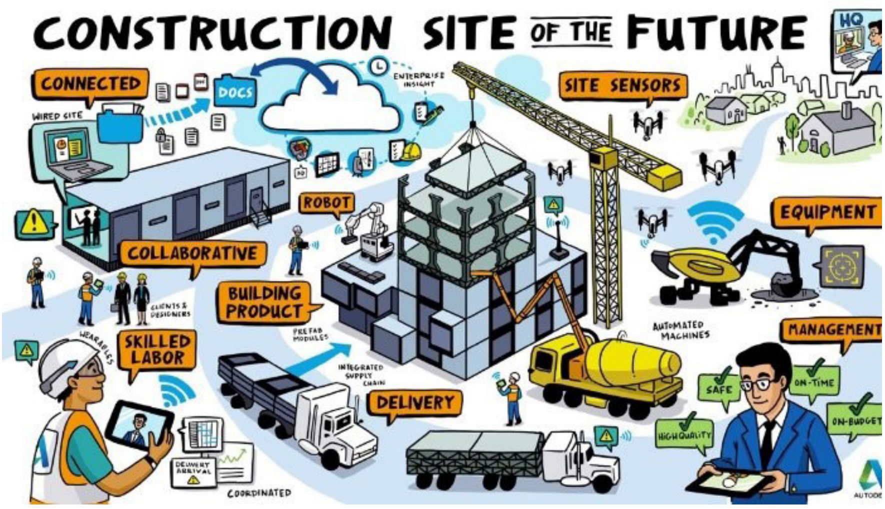

Figure 4: the 4.0 construction site. Thanks to the wide use of sensors, digital dynamic models of building and improved human-machines interfaces, is possible to manage collaboratively the Building process, in a safer way. From LinkedIn, J. Gall, 2016

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19

A Literature Review on BIM Maturity in the AECO Industry

KEYWORDS: Performance measurement, BIM, BIM maturity, Maturity levels, Bibliometrix.

Physical assets are, nowadays, more and more included in the digital environment, providing huge amount of data, and involving a complex network of stakeholders. Many Information Communication Technologies (ICTs) are employed in Architecture, Engineering, Construction and Operation (AECO), in order to tackle the digital transformation. Currently, one of the most acknowledged approaches for managing the new complexity of the built environment is Building Information Modelling (BIM). This article addresses the issue of the maturity of organisations, which adopt or are willing to adopt a BIM approach. Therefore, research aims at providing a critical review on BIM maturity of organisations operating in AECO. The BIM approach can be considered a step forward for supporting the development of digital processes able to foster the achievement of their business objectives. The scope of the research concerns the overall dynamics of the AECO sector concerning the digital revolution affecting management of the built environment processes along the life cycle of physical assets. Therefore, a literature review on Scopus databases has been carried out and most relevant dynamics in the literature production have been identified and investigated trough bibliometric, trend and cluster analyses carried out on the selected sample of articles. In summary it can be stated that the BIM maturity allow to evaluate organisations' digitalisation potential enabling the reengineering of business processes. Moreover, the evaluation of organisations' BIM compliant approaches can provide a sound assessment method during a bid process, contributing to the transparent and effective selection of the most virtuous firms.

INTRODUCTION

The built environment, today, is more and more characterized by the digitalization of processes, from the early stages of the design, until the decommissioning of the assets (RIBA 2013). This trend leads to the massive employment in Architecture, Engineering, Construction and Operations (AECO) of digital tools able to manage the information complexity provided by the digitalised built environment. Within this context, one of the most acknowledged and recognised methodology for information management is Building Information Modelling (BIM) approach. According to the framework defined by the British Standard Institution (BSI, 2014), BIM can be intended as the management of information flows along the life cycle of the asset through the use of digital modelling (British Standard Institution 2018), namely a set of digital processes, enabled by digital tools, procedures, methodologies, furthering efficiency of the information exchange and collaboration among players.

Despite the clear advantages offered by this powerful approach, still its adoption seems to be not completely embedded in the attitude of the AECO players. This is probably due to the need for a paradigm shift in the behaviour on the market of these subjects that often seems to be not completely aware of the remarkable benefits that could be achieved in the middle-long term perspective (Pärn, Edwards, and Sing 2017). Therefore, the research aims at providing a critical review on BIM maturity of organisations operating in AECO.

THE BACKGROUND OF THE RESEARCH

Many approaches for the BIM performance measurement can be found in literature (Yang et al. 2010; Andone 2009; Shin and Chai 2016; Chen, Dib, and Cox 2014; Giel and Issa 2014; Kassem, M.; Succar, B.; Dawood 2012). Nevertheless, the most part of them agree with the definition of two fundamental terms: (i) adoption, and (ii) maturity. The former concerns the ability of an organisation of handling BIM tools, and delivering BIM based products, according to increasing levels of skills. The latter quantifies the capability of an organisation to provide standardised guidelines, and procedures, to be distributed among its members, and to be applied whenever a BIM output must be achieved (Bilal Succar, Sher, and Williams 2013). Therefore, while the BIM adoption can be considered a bottom-up approach, the BIM maturity should be considered as an issue which can be addressed according to a top-down approach: the management of the organisation must be aware of strategic choices and advantages coming from the adoption, standardisation, and implementation of the BIM approach.

The resistance to the digitalization of AECO market

According to the report published by McKinsey Institute (McKinsey Global Institute, 2017) on labour productivity, it is interesting to analyse data on digitalization. Namely, construction sector is following both in term of productivity, and digitalization all the other sectors, especially manufacturing, and agriculture. Literature shows clearly the benefit that BIM can provide to AECO industry (Gurevich and Sacks 2014; Alvarenga 2017; Al Hattab and Hamzeh 2015; Sacks et al. 2010; Rischmoller, Alarcón, and Koskela 2006; Jeong et al. 2016). According to data of Eurostat, and Italian Office for National Statistics, a burden factor is the ratio between the value of investment in engineering the project, and the whole sector value, showing a value of 0.12 in Italy compared to the 0.23 in G7 area. This comparison highlights the low investments in the engineering component of the process compared to the whole industry. This factor shows the low interest of the sector in changing. Focusing on the Italian public sector, an analysis of the design tenders awarded through Most Economically Advantageous Tender (MEAT) processes published in 2017 (OICE 2018), shows an average award with 30 out of 100 points assigned to the economical factor. The public administrations bend the use of the MEAT process to a call for tenders which evaluates just the economic factor. This approach less and less enhances the project engineering, which could provide a remarkable optimization of the final product (Philipp Gerbert 2016) (i.e. in terms of sustainability, performance, cost, etc.). This approach imposes a lot of collateral costs in construction phase (Love et al. 2011), BIM approach could reduce all these variance in performances (Peansupap and Ly 2015). Design firms react to this reluctance to investment reducing the effort on the final product. Firms invest in the project less in order to maintain profitability, due to the huge discount offered during the tender(Baddeley and Chang 2015). This attitude, on behalf of the contracting authorities, outlines an inherent condition of the sector that leads it to analyse just investments in the short term(World Economic Forum 2017).

SAVINGS VERSUS QUALITY IN THE PUBLIC TENDERS

A second consideration concerns the average discount carried out by the firms that won design tenders. According to data published by the Italian association of Italian engineering, architectural and technical economic consulting organizations (OICE 2018) in June, the reduction in terms of price, between the pre and post awarding procedures, is 30.2% for tenders published in 2014 and 40.0% for those published in 2015. The tenders published in 2016 reached an average decrease of 43.0% and

those published in 2017 had an average decrease of 40.9%.
This situation is empathised especially considering the trend of the discount average of design tender. This attitude of offering a service at a high discount provides a decrease in the quality of the service (Aziz and Hafez 2013). Namely, it provokes an approach where there is a reluctance to innovation, in particular of new methodologies, such as BIM (Murphy 2014). According to NBS (Waterhouse and Philp 2016; Waterhouse et al. 2018), the BIM approach is not perceived by all designers, and contractors as an advantage to have a holistic view of the project, and provide a better result, but as a requirement of the clients. Namely, Public Authorities require BIM even if they do not have a clear knowledge of what they can achieve through the application of this methodology. For this reason, the computational approach is possible only if the clients, and the people who really want to apply this methodology are well focus on the objective. Moreover, a deeper knowledge and awareness of potentialities offered by the adoption of the BIM methodology is required to foster the virtuous processes.

THE AIM OF THE RESEARCH

The aim of this paper is to provide a critical review on the measurement of the BIM maturity level of organisations, which adopt or are willing to adopt a BIM approach.
This work sets the foundation to understand the lacks in the state of the art, and the interests of the industry. In order to obtain this result, the research provides a comprehensive critical overview of the scientific theoretical framework starting from the market conditions and behaviours. The investigation is conducted on the historical trend to outline and forecast the trend of AECO interest.
Therefore, a set of bibliometric analysis have been carried out, on a selected sample of references retrieved from Scopus database. The references have been processed through Bibliometrix (Aria & Cuccurullo 2017): an R-tool allowing many bibliometric analyses, clustering and mapping operations. The paper concludes with some insides in the knowledge gaps emerged from the bibliometric and suggest future research trajectories.

METHODOLOGICAL APPROACH

The critical literature review on BIM maturity has been implemented thanks to the use of the R-tool Bibliometrix (Aria and Cuccurullo 2017). Bibliometrix allows to exploit a set of functions able to provide a comprehensive view of a specific sample of references. The sample has been retrieved from Scopus, one of the most acknowledged and reliable databases of scientific literature. For the selection of the sample, the following keywords have been used: BIM OR "Building* Information Modeling" OR "Building* Information Modelling" OR "Building* Information Model" AND Maturity and the Scopus database has been inspected in fields “Article title, Abstract, Keywords”. The research has been carried out in early July 2018. A wider set of references would have been retrieved if all fields in the database had been inspected, though the reliability of data collected would have been reduced remarkably.
Despite the topic of the maturity level is well defined and the boundaries are recognisable, the BIM in literature is defined in different ways according to the regional provenance of the authors and to their own personal choices. Therefore, many definitions of the keywords have been employed: BIM or "Building* Information Modeling" or "Building* Information Modelling" or "Building* Information Model". The research provided as outcome 110 references.
The following step concerned the cleaning of the selected references, since some of them are not associated to an author (authors field is marked as [No author name available]).
This operation gave as output a database of 100 references. On the cleaned database the bibliometric analyses have been carried out and key insights have been identified. Analyses can be divided in five groups.
The first group concerns the general knowledge of the database. These statistics summarise information as the number of total documents retrieved, the number of sources, number of keywords etc (Table 1). The first group is followed by four thematic sets of analyses concerning the chronological distribution of the scientific production, analysis by author, by country and the thematic analyses of the keywords. The discussion of these results allows to spot the gap in literature and main characteristic of the literature production on the measurement of the BIM maturity level in Scopus database.

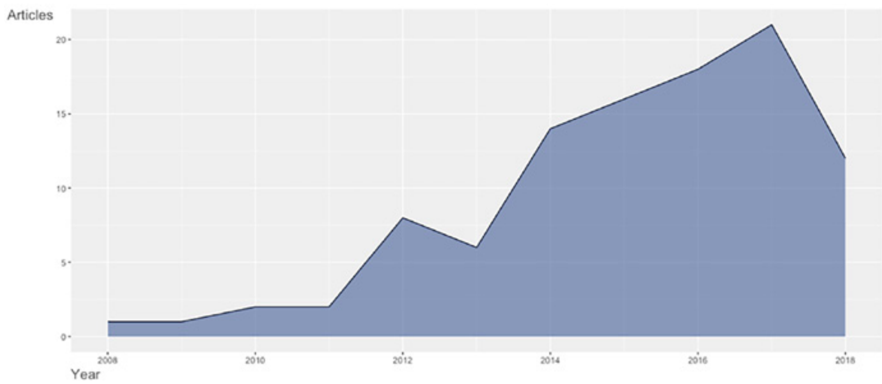
LITERATURE REVIEW AND ANALYSIS

Table 1 summarises the main statistics performed through the use of Bibliometrix. As can be seen, the number of papers retrieved after the cleaning process is great enough to perform some substantial statistics, despite 100 are not representative of a wide literature production on the BIM maturity from 2008 to 2018. Nevertheless, the high number of citations per documents shows a potential high interest in the topic.

Historical series

The increasing interest in the topic is also confirmed by the scientific production over the years, with a particular increasing of publications from 2011 to 2017-18 (Figure 1). The adoption of BIM became in these years a hot topic in many countries.
This trend is also confirmed by an increasing number of papers published in conference proceedings in the timespan indicated above. A slower growth is registered from 2008 to 2011, though the annual percentage growth rate is 28.21%. Despite the scientific production shows a rapid increasing from 2011 to 2018, a countertrend dynamic can be observed for what concerns the average total citations per year (Figure 2). In 2009, in this case, a peak of more than 350 total citations is registered.
The number of citations, if taken as a single index, do not express the quality of scientific production. In fact, the interest on the topic started growing since the first highly cited publication (B Succar 2009), since then only a few publications on the topic were made compared to the actual production. From that moment on, the literature production rose exponentially. This trend could explain the decreasing of average citations per year after the 2009.
Analysis by author
Further analyses concerning the authors' productivity have been done. At first a ranking of most productive authors in the timespan 2008-2018 has been developed (Figure 3).

Documents	*100*
Sources (Journals, Books, etc.)	*72*
Keywords Plus (ID)	*679*
Author's Keywords (DE)	*266*
Period	*2008 - 2018*
Average citations per documents	*10.07*
Authors	*257*
Author Appearances	*289*
Authors of single authored documents	*9*
Authors of multi authored documents	*248*
Documents per Author	*0.393*
Authors per Document	*2.54*
Co-Authors per Documents	*2.86*
Collaboration Index	*2.82*



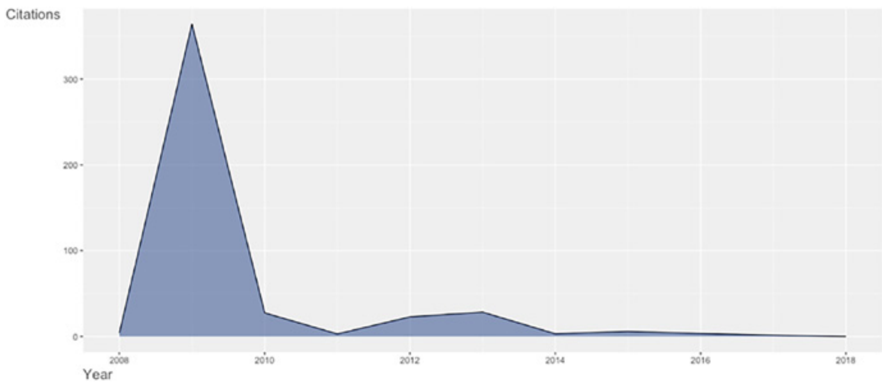


Table 1: Main Information about data.
Figure 1: Annual scientific production over the total sample of references
Figure 2: Average total citations per year

Afterwards, authors have been related among each other, as represented in Figure 4, through the authors' coupling function. Two articles are coupled if at least one cited source appears in the list of references of both articles. A coupling network can be created using the formula:

$$B_{cocit} = A \times A'$$

Where A is a Document X Cited reference matrix (Aria and Cuccurullo 2017).

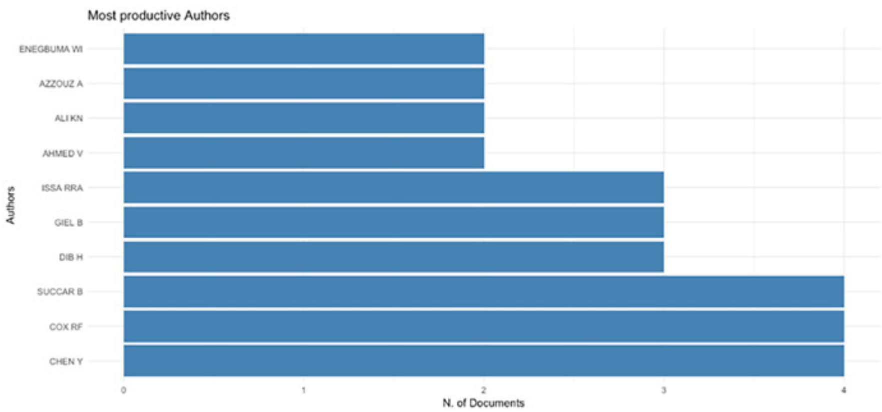
For the analysis carried out in Figure 4, the unit of measure considered is "authors", alternatively can be used other unit of measures as "references", "sources", "countries", "keywords" etc. Figure 4 shows that most productive authors are related among each other.

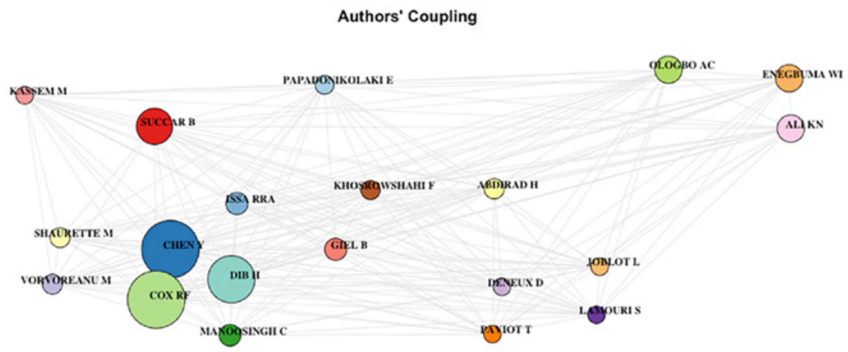
Analysis by country

For the analysis of the publications, carried out following a similar approach, most productive countries have been identified and represented (Figure 5) as well as the relationship among them (Figure 6). For synthesis reasons, as in previous representations, only the first 10 most productive countries have been plotted (Figure 5), while in Figure 6 all the provenance of authors have been represented. Figure 5 demonstrate that the most part of the documents can be categorised as Single Country Publications (SCP). Arguably, this is due to the scholars' inclination to collaborate in writing articles among their own local research group.

Only Australian publications show a majority of Multiple Country Publications (MCP) against SCP. Figure 6 has been obtained in a similar way compared to Figure 4. In this case the country collaboration is calculated as a relationship where the nodes are the provenance of authors (countries) and the links are co-authorships. This relationship can be obtained thanks to the formula:

$$B_{coll} = A' \times A$$





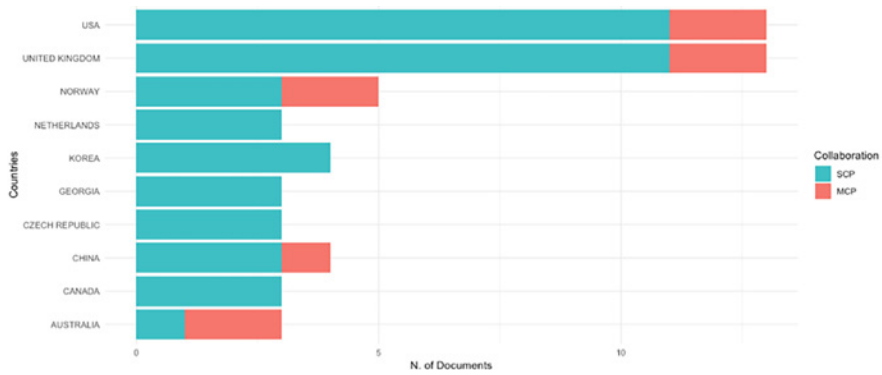


Figure 3: Most productive authors from 2008 to 2018
Figure 4: Authors' couplings among the most frequent 20 authors
Figure 5: Most productive countries: Single country publications (SCP), Multiple Country Publications (MCP)

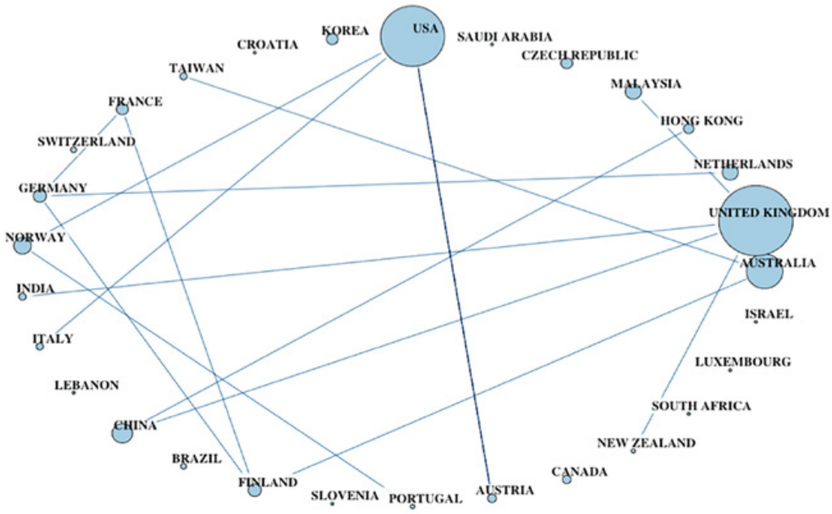
where A is a Document × Author matrix (Aria and Cuccurullo 2017).

Keywords analysis

A further step concerns a set of analyses on the keywords retrieved from selected articles. These operations have been carried out thanks to a refinement of data. The main issue in this phase concerns the definition of Building Information Modelling.
According to the provenance of the authors and to narrative choices, BIM can be named differently: “Building Information Modeling”, “Building Information Modelling”, “BIM” and combinations of the first two alternatives with the third. In order to gather all terminology with the same meaning, we decided to redefine all the different alternatives as “BIM”. Nevertheless, this operation give rise to the loss of the heterogeneity of the definition of the term; though it allows to group all terms with the same semantics in a single entity.
Moreover, a network and clustering analysis have been carried out (as for analyses by author and by country) using the following formula:

$$B_{coc} = A' \times A$$

The R-package employed for the analyses allow to obtain a further semantic representation of the keywords analysed.
Therefore, Figure 9 represents the conceptual structure map obtained through a Multiple Correspondence Analysis (MCA) which allows the data interpretation according to the relative positions of the points representing a specific author keyword and their distributions in the graph. As words are more similar in distribution, the closer they are represented in the map (Aria and Cuccurullo 2017).



Author Keywords (DE)	*Articles*	*Keywords-Plus (ID)*	*Articles*
Bim	61	Bim	43
Maturity	8	Construction Industry	26
Bim Maturity	5	Information Theory	23
Information Technologies	5	Buildings	13
Construction	4	Information Management	13
Construction Industry	4	Construction	9
Implementation	3	Construction Projects	8
Information Systems	3	Project Management	8
Information Technology	3	Information Technology	7
Lean Construction	3	Maturity	7

Figure 6: Country collaboration
Table 2: Most frequent keywords. DE are the Author Keywords and ID are the Keywords associated by Scopus (first 10).
Figure 7: Conceptual structure map

DISCUSSION

The analysis of the scientific production on this topic meets the evolution of the Hype cycle (Fenn and Raskino 2008). The increase of the technology applications, supporting the methodology, is reaching its pick of inflated expectations (Waterhouse et al. 2017, 2018). In fact, considering the historical series, the literature production raised a lot from 2009 until the first half of the 2018, especially forecasting the annual scientific production the trend is increasing. This evolution is caused by a demand to the BIM methodology that, most of the time, results in a simple translation of a traditional process into a digitalized one, particularly when alphanumeric information are not relevant compared to graphical ones. Analysing the literature review published at international level, there are a few authors with high number of citations. These authors are tightly linked as well. The most productive countries are connected, but this connection is not structured between the USA and UK, which are, beside all, the most productive ones. The research individuated, in the analysis of the keywords used by authors, that there is a slight alteration of the key topics due to the multiple ways of defining the BIM acronym. Indeed, the authors realigned these words to a common topic and obtain a result characterised by an improved semantic meaning. Therefore, according to Figure 9, two main semantic groups of keywords can be identified, the first regards the process management and the theories and best practices of BIM maturity models' assessment and application, the second is related to life cycle management. These two sets can be intended as the edges of the disciplinary fields which encompass the topic of the BIM maturity. On one hand these two sets represent the most suitable environment for publications, on the other hand, they can be taken as starting point for the development of new theories and practices in other contexts.

CONCLUSIONS

Through the use of Bibliometrix, the authors developed a set of comprehensive bibliometric analyses in a streamlined way analysing and clustering the results. This approach allows to understand a massive amount of data looking into its complexity. Moreover, the research provides a solid method to understand the boundary of the evolution of the literature, despite an extension of the set of articles (e.g. considering other databases as Web of Science, Scholar, etc.) could improve the analyses and provide further meanings. Also, grey literature (reports, whitepapers etc.) has not been considered, despite it could be representative of other dynamics in literature as the adoption of the BIM by institutions and firms and may refine the conceptual structure map. The critical review helps in a better and more accurate definition of the boundaries of the BIM maturity which allows to evaluate organisations' digitalisation potential, enabling the reengineering of business processes. Moreover, through the evaluation of the companies' processes compliance with the BIM approach, a more reliable assessment during the bidding process could be achieved. This trend contributes to the transparent and effective selection of the most virtuous organisations.

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20

Using Genetic Algorithms for Optimizing and Modelling Time, Cost and Quality Trade Offs of Construction Projects

KEYWORDS: Construction, Project Management, Genetic Algorithm, project planning, time-cost-quality trade-off.

The well-known "iron triangle" and its attributes, time, cost and quality has still importance as a framework of basic objectives of construction projects. In practice, construction project managers can optimise time and costs with the well-known time/cost trade-off approach, but quality optimization versus cost and time performances in construction project is usually pursued in a rather intuitive manner based upon Project Manager's experience. The research behind this paper is proposing a specific approach where three possible estimates for time, cost and quality form starting points for the optimisation of project performance. The estimates are based on characteristic of alternative technical solutions such as possible commercial products to be used or assembled. The effectiveness of various combinations is evaluated with an optimisation procedure based upon Genetic Algorithms. A simple pilot study of a renovation project of two residential apartment is presented to test the proposed approach. The gained results are demonstrating the possibilities of genetic algorithms for such trade off analyses.

INTRODUCTION

Quality in construction projects is of prime importance for the final client. Time and cost are other main points of interest, but the desired quality of an important construction project can be an outstanding result to achieve. Project Manager's objectives are often described as the "Iron Triangle" (Atkinson, 1999), meaning time, cost and quality or project scope. Generally speaking, quality can be defined as the fitness for purpose, while more stringent definition is the degree of conformance of the outputs and process (APM, 2015) and the level of accomplishment of a product or a process to a set of performance requirements (ISO 9000:2005). ISO standards define quality as the degree to which a set of inherent characteristics fulfill requirements. Quality assessment in construction can be divided into three main components: quality of products, quality of design and quality of processes. Quality of products can be understood primarily as a technical quality whereas quality of design is about meeting the needs of client and end users successfully.

The quality of processes refers all activities throughout the life-cycle of building construction project (Bragadin, Kahkonen, 2013).

Traditional project control techniques are built around time and cost, where estimates of costs and durations of work packages and finally over the total project are forming the control baseline. The integrated project control of time and costs generally is addressed with the Earned Value Method (Moder et alii, 1983, Rasdorf and Abudayyeh, 1991, ANSI/EIA, 1998). Time-cost trade-off is a well known method of project management (Fondhal, 1962; Harris, 1978; Moder et alii, 1983; Reda, Carr, 1989; Fan, Lin 2007, Agdas et alii, 2018) that aims at optimising project results in terms of cost and timing, mainly by evaluating the ratio between the differences of crash cost and normal / minimum cost and crash duration and normal duration of activities on a critical path.

Nevertheless, few optimisation approaches that entails also quality can be found in literature (Minchin, Smith, 2001; El-Rayes, Kandil, 2005, 2006; San Cristobal, 2009; Monghasemi, Nikoo, Fasaee, Adamowski, 2015). Project quality is surely interdependent with time and costs, but a general mathematical equation that links the three KPIs can be difficult to find, or at least, can be different changing from case to case. Project Managers, actually, optimise quality versus costs and time with a rather intuitive manner.

Framing the quality and integration of the quality aspect with the time and cost aspects have been long-term topics of interest both to the industry and academia. The quality of construction is closely relating to the value and performance concepts. Solutions such as value engineering and management, Quality Management Systems (QMS) together with key performance indicators (KPI) represent solutions in practice that are framing quality and providing some linkage to time and cost. Modelling of interplay between time, cost and quality has been a long term arena of interest particularly for academia.

Quality assessment in management of construction projects can be successfully delivered with quality based KPIs (Minchin, Smith 2001; El-Rayes, Kandil, 2005, 2006), and the objective of the presented research work is to propose Genetic Algorithms to purse time-cost-quality trade-offs in construction projects.

PREVIOUS WORK

Few researchers focused the problem of the evaluation of the global quality of a project or a system by means of a quality indicator, and the development of a time-cost-quality trade-off procedure. Atkinson (1999) introduced the concept of the project manager's iron triangle, meaning the need of integrating time, cost and scope, or quality project objectives. The integration of cost, schedule and performance data was addressed by Cho, Russell and Choi (2013) building on the traditional Work Breakdown framework.

In the field of Information Technologies Mishra and Mahanty (2014) indicate that the optimisation of project cost, schedule and quality for a software development project in an outsourcing environment, can be studied with a system dynamics simulation approach.

El Rayes and Kandil (2005, 2006) presented a method aimed at facilitating the measurement and quantification of the global construction quality by estimating quality performances of each project activity thorough the definition of a Quality Index. The method was applied in the field of highway construction. The definition of a quality KPI, termed Quality index, is achieved by the creation of a Quality Breakdown Structure (QBS) of the project. The Construction Quality Index (CQI) is a rating of quality of materials and workmanship on highway projects completely objective (Minchin, Hammons and Ahn, 2008).

The QBS developed approach builds on the "Quality – Based Performance Rating System" of the American National Cooperative Highway Research Program (NCHRP) (Anderson and Russel 2001, Minchin and Smith 2001) for contractors' qualification. QBS aims at evaluating the final quality of the products of the construction process, with a performance-based approach. Therefore, a set of quality indicators are detected to evaluate the final product quality.

An automated optimisation system for construction resources termed MACROS, was developed (El Rayes and Kandil, 2005, 2006), and the time, cost and quality trade-off algorithm is developed by Genetic Algorithms.

The use of Genetic Algorithms (GAs) was introduced by J. H. Holland (1975) as a research method based on the mechanics of natural selection and natural genetic of Darwin's Evolutionary Theory. Later, Goldberg (1989) developed further the GAs approach in the field of automation engineering. GAs have been implemented in many engineering and operations research problems, for instance the Travelling Salesman Problem (Razali, Geraghty, 2011).

San Cristobal (2009) proposed an Integer Programming model which enables meeting quality output standards and time and cost objectives respectively, while Monghasemi et alii (2015) propose a

Multi-criterion decision-making approach that identifies all global Pareto optimal solutions by a multi-objective Genetic Algorithm. Sorrentino (2013) applies GAs to a time, cost and quality optimisation problem for project scheduling of road construction and finally Tiene (2017) investigated a similar application for the selection of design alternatives for a building envelope.

GENETIC ALGORITHMS FOR TIME, COST AND QUALITY TRADE-OFF

Owners and Government agencies have placed an increasing pressure on decision makers in the construction industry to design and plan new construction projects minimizing construction costs and time while maximizing its quality (San Cristobal, 2009). A custom Genetic Algorithm (GA) is developed and used to solve the time- cost and quality trade-off problem.

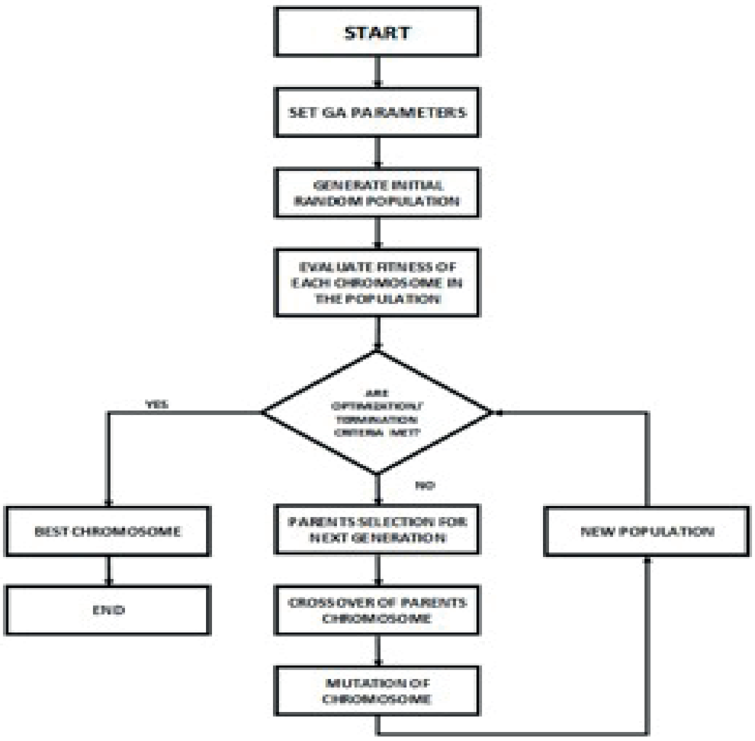
Genetic Algorithms (GAs) are a global and stochastic research method termed “genetic” because of the mutual terminology from genetics, a branch of biology. Genetic algorithms are probabilistic search procedures designed to work on large spaces involving states that can be represented by mathematical strings (Goldberg & Holland, 1988). Genetic algorithms can be used with the aim of planning and controlling the activities of a project as they are search and optimization tools that assist decision makers in identifying optimal or near-optimal solutions for problems with large search space.

One fundamental advantages of GAs from traditional methods is that they work from a rich database of solutions simultaneously (a population of chromosomes), climbing many peaks in parallel, thus the probability of finding a false peak is reduced over methods that go solution to solution, like the “brute-force” method. The basic structure of a genetic algorithm involves cyclic operation that simulates the evolutionary process of a population. Each loop represents one generation and each new population generated is formed by better and better individuals. Five phases are considered in a Genetic Algorithm: initial population; fitness function; selection; mating (crossover / mutation); termination.

A typical genetic algorithm starts generating randomly an initial population of possible solutions, called individuals. Every individual in the population (or whatever solution is desired) is coded in the form of a string, called the Chromosome. Each member of the current population is assessed by calculating its fitness value by the objective function (fitness), and an appropriate sorting of these individuals is determined on the basis of the fitness values: The most promising individuals are selected as parents, creating a sequence of new populations or generations.

After selecting an n number of individuals, the genetic algorithm emulates the sexual reproduction that occurs naturally in biology and re-combines the genetic material of the parents, giving birth to the children or to the future generation of solutions. The re-combination is carried out by genetic operators of Cross Over (by appropriately combining the characteristics of a couple of parents) and Mutation (by making random changes on a single parent). The new generation of solutions takes the place of the previous generation, from which it was born for re-combination. The process is repeated a great number of times until one of the stop requirements is fulfilled (termination), for example when an acceptable approximation of the solution to the problem is reached, or the maximum number of iterations has been performed. In figure n. 1 a flow chart summarizes the operating principles of GAs. The GA approach is set on a population that generates a set of possible solutions. Subpopulations are possible, and subpopulation structures termed species can be defined with different approaches.

Genetic algorithms do not ensure that an optimal solution is found but contribute to a set of solutions superior to the source solutions. From the same problem and from the same set of possible starting individuals at each new population



generation the individuals evolve towards different and better new solutions. Because of this the GAs are used in the study of artificial intelligence. In many situations, there are more than one relevant goal to minimize (or maximize), in this case a multi-objective genetic algorithm is defined. A multi-objective GA pursues multiple objectives simultaneously, in the sense that an individual is considered more or less suitable in relation to multiple criteria. In this case the problem to be addressed is not simply reduced to the search for a local (or global) maximum or a minimum for a given function, but to the analysis of multiple criteria at the same time. In this kind of problems the various objectives are often conflicting, meaning that a solution that minimizes or maximizes an objective will generally not minimize or maximizes others. In a multi-objective optimization problem, there is a need to find a solution that is optimal at the same time for all objective functions that describe the problem.

GA MODEL IMPLEMENTATION: PROPOSED APPROACH

The GAs implementation is based upon a table that reports the needed data for genetic algorithm implementation. A table summarizes for each project activity the alternatives related to activity duration, activity cost and quality (table 1).
Therefore, each project activity includes three possible options for its development that creates a search space of thousands of possible solutions. GA – based algorithm has been implemented with Matlab®. This application is able to explore the solution space very quickly and can identify a set of optimal solutions. The pilot study has 21 work packages (WP), and each has three possible alternative of time, cost and quality to create project activities. The possible combinations of these alternatives create a large space of search, where each solution in this space can be a possible option for project delivery.
Nevertheless, the search space is not 321 because different subpopulations, termed species, constitute the structure of base data of the problem. In fact, project modelling can be represented with a time-oriented networking approach (fig. 2). Therefore, each possible path from project start to project finish constitutes a species. Within species, i.e. single path, permutations of different WP alternatives are possible, after satisfaction of precedence relationships between succeeding WP. No alternative permutations are possible between different species because of the structure of chromosomes, i.e. the number of WP of each network path. Every project activity can be represented by a 3-by-3 matrix reporting the options in terms of time-cost-quality.
Therefore, the whole project is represented by a set of matrices divided into different species that constitutes a data array from which activity performance data are selected to create the chromosome of a single species.
The chromosome of a species is created by time, cost and quality data of each chosen WP alternative belonging to a network path.
An initial random selection of options for each activity is performed and the corresponding objective function is computed. Next, GA uses genetic operators such as crossover, which divides two initial solutions exchanging their chromosomes in order to generate new solutions, and mutation, that simulates the effect of random errors. The new solution is computed again and the results of the objective function are compared with the previous ones. The best solutions are selected in order to improve the fitness function. Each solution has a fitness value different from the others and best solution are selected for future generations while worse solutions are set aside.
Final evaluation of the found solutions can be performed by comparison with maximum and minimum set limits of the three parameters, termed Cmax, Cmin, Tmax, Tmin, Qmax and Qmin. Anyway, the objective of the optimisation is to find a solution that minimises times and costs, while maximises quality. Therefore, the proposed fitness function depends on the three WP parameters (time, cost and quality) weighted . The following equation (1) is proposed.

$$Fitness = \max\left(\frac{Ci \times Kc + Qi \times Kq + Ti \times Kt}{3}\right)$$

Where Ci is defined by the following:

$$Ci = 1 - \frac{\sum Cj - Cmin}{Cmax - Cmin}$$

Where ΣCj is total cost of each j work package of the project (j = 1, 2, 3, ….n) of each i generation (i=1, 2, 3, ……m) and m the number of generations.
Qi can be found by the following equation:

$$Qi = \frac{\sum Qj}{n}$$

Where ΣQj is the total sum of quality indexes of each j work package of the project (j = 1, 2, 3, ….n) for the generation i and n the total number of work packages of the project.
Ti is the time parameter found for the i generation, defined by the following:

$$Ti = 1 - NTd$$

Where NTd is the normalized total duration:

$$NTd = \frac{TDi - Tmin}{Tmax - Tmin}$$

Where TDi is the total project duration found by network diagramming and critical path computation for the generation i. TDi is the maximum duration found by critical path analysis comparing each total duration TDik of a single species k of the generation i composed by the work packages j belonging to the k network path.

$$TDi = \max TDik$$

The weighting parameters kc, kq and kt can range from 0 to 1 for cost, quality and time, respectively. Aiming at balancing the three parameters the following values has been set: kc = 1; kq=1; kt=1.

PILOT STUDY APPLICATION

A simple pilot study of a renovation project of two residential apartment has been imp to test the proposed approach. For each work package, three different commercial product options has been considered and corresponding activity durations, costs and quality performances have been detected from a public works price list (Regione Lombardia, 2008). Quality indexes has been evaluated straightforwardly as product quality and its suitability for the use. Therefore, the proposed time – cost – quality trade-off procedure has been implemented using Genetic Algorithms, with the aim of finding a set of optimal solutions for the building construction project. Found data for each work package are presented in table 1a and 1b.

A project model has been implemented with network diagramming. Therefore, critical path analysis can be performed and total project duration can be found for each project alternative of the pilot project (fig. 2).
Firstly, the limits of possible solutions concerning different WP alternatives have been selected. Minimum and maximum total values of the three project parameters, time, cost and quality, have been computed by selecting the corresponding alternative for each WP (table 2).
Secondly, the Matlab application has been set for the specific problem. The network diagram and the working options of the pilot study have been formalized in Matlab® using two classes (one for describing the work package and one for the work package options). Beyond class attributes like code and description, other network attributes, such as the set of successors of each work package, or the set of option belonging to each work package were added. The whole problem has been translated into the Matlab® code. The maximum number of generation has been set to 100 and the stall condition to 50 generations. After running, the GA correctly converges to optimal solutions, reaching the best fitness scores generally just after 60-70 generations (see Figure 3). Both the fittest individual (Figure 3 –

A	C	D		E	O
No. / WP alternatives	WBS	Work Package description	Quality index (%)	Cost (€)	Duration (h)
1	A.01	demolizioni e rimozioni			
A		demolizioni e rimozioni A	90%	€ 15.174,00	177
B		demolizioni e rimozioni B	100%	€ 15.345,85	177
C		demolizioni e rimozioni C	110%	€ 15.409,35	179
	A.02	murature			
2	A.02.01	riparazione scuci cuci di murature			
A		mattoni pieni	100%	€ 18.225,22	248
B		mattoni semiartigianali tipo antico	110%	€ 30.846,14	307
C		mattoncini realizzati a mano tipo antico	90%	€ 35.972,56	308
3	A.02.02	tramezzi in mattoni forati cm 8			
A		mattoni a sei fori 8 x 14 x 28	100%	€ 592,08	8
B		foratelle a dieci fori 8 x 25 x 25	90%	€ 572,64	7
C		tramezzature di gesso in pannelli spess. Cm8	120%	€ 738,24	8
4	A.02.03	tramezzi in mattoni forati cm 10			
A		mattoni a sei fori 10 x 14 x 28	100%	€ 1.540,59	19
B		tramezzature di gesso in pannelli sp. cm10	110%	€ 1.839,02	20
C		tramezzature latero-gesso pann. Sp. Cm 10	120%	€ 2.304,46	21
	A.03	Sottofondi - massetti			
5	A.03.01	massetto isolante alleggerito polistirene espanso			
A		massetto isolante alleg. polistirene espanso	105%	€ 3.379,20	34
B		massetto isolante alleg. sughero naturale	100%	€ 4.878,40	34
C		massetto isolante alleg. vermiculite espansa	90%	€ 5.156,80	33
	A.04	Intonaci			
6	A.04.01	intonaco premiscelato per interni			
A		intonaco civile interni malta bastarda	100%	€ 4.994,08	83
B		intonaco civile interni malta di calce spenta	110%	€ 4.877,60	82
C		intonaco civile interni malta di cemento	90%	€ 4.994,08	82
	A.05	Pavimenti Rivestimenti			
7	A.05.01	pavimento in gres porcellanato 40x40 granigliato			
A		pavimento in gres porcellanato 40x40 tin. Unita	100%	€ 2.837,97	18
B		pavimento in gres porcellanato 60x60 tin. Unita	110%	€ 4.874,85	14
C		pavimento in gres porcellanato 20x20 tin. Unita	90%	€ 2.497,11	18
8	A.05.02	rivestimento in piastrelle ceramica mono. 20x20			
A		rivestimento in piastrelle ceramica mono. 20x20 tinta unita pastello	90%	€ 6.261,71	49
B		rivestimento in piastrelle ceramica mono. 20x20 effetto marmorizzato	100%	€ 3.632,72	49
C		rivestimento in piastrelle ceramica mono. 10x10 effetto pietra	110%	€ 7.433,79	60
9	A.05.03	zoccolino battiscopa in gres			
A		zoccolino battiscopa in gres 10x20	110%	€ 2.504,80	21
B		zoccolino battiscopa in klinker 8x24 smaltato	100%	€ 1.700,00	17
C		zoccolino battiscopa legno prever. Ciliegio 75x10mm	80%	€ 1.201,60	9

A	C	D		E	O
No. / WP alterna-tives	WBS	Work Package description	Quality index (%)	Cost (€)	Dura-tion (h)
	A.06	infissi e porte			
10	A.06.01	fornitura e posa struttura metallica di sostegno porte scorrevoli - scrigno			
A		Struttura metallica sostegno porte scor.scrigno	100%	€ 511,28	3
11	A.06.02	fornitura e posa controtelai porte larghezza fino 11 cm			
A		controtelaio in abete sp. 2,5 cm largh. 11 cm	100%	€ 93,60	1
12	A.06.03	fornitura porte in legno tamburato anta cieca liscia noce			
A		porte interne anta cieca liscia noce tanganika	90%	€ 2.412,84	8
B		porte interne anta cieca liscia noce nazionale	120%	€ 3.855,00	7
C		porte interne anta cieca liscia rovere naturale	100%	€ 3.209,88	8
	A.07	impianto elettrico			
13	A.07.01	impianto elettrico			
A		impianto elettrico opzione A	100%	€ 2.200,00	21
	A.08	impianto idrico sanitario			
14	A.08.01	fornitura e posa di vaso igienico monoblocco a pavimento			
A		vaso igienico vetrochina in opera escluso op.mu.	100%	€ 473,50	5
B		vaso igienico vetrochina sospeso escluso op.mu.	110%	€ 629,10	5
C		vaso igienico vetrochina sospeso cromato escluso op.mu.	120%	€ 1.034,08	6
15	A.08.02	fornitura e posa di bidet			
A		Bidet in porcellana vetrochina escl. Op. murar.	100%	€ 469,26	4
B		Bidet in porcellana sospeso NP	110%	€ 625,10	5
C		Bidet in porcellana sospeso cromato NP	120%	€ 1.030,08	6
16	A.08.03	fornitura e posa di lavabo 65x50			
A		lavabo in vetrochina 70x55	100%	€ 687,84	5
B		lavabo in vetrochina 65x50	95%	€ 643,20	5
C		lavabo in vetrochina 70x55 con colonna	105%	€ 842,06	6
17	A.08.04	fornitura e posa scarichi in pvc per bagno			
A		rete di scarico per bagno in pvc	100%	€ 629,12	8
18	A.08.05	rete generale di distribuzione acqua calda/fredda			
A		rete d. acqua calda/fredda polibutilene	100%	€ 967,00	9
B		rete d. acqua calda/fredda acciaio zincato	95%	€ 1.156,64	18
C		rete d. acqua calda/fredda polietilene reticolato	105%	€ 1.366,44	17
	A.09	assistenze murarie			
19	A.09.01	assistenze impianto idrico sanitario - esecuzione tracce e fori	100%	€ 640,00	11
20	A.09.02	assistenze impianto elettrico	100%	€ 880,00	15
	A.10	opere da pittore			
21	A.10.01	tinteggiatura interna con idropittura traspirante			
A		tinteggiatura interna idropittura traspirante	95%	€ 3.648,20	55
B		tinteggiatura interna idropittura traspir. Lavabile	100%	€ 4.077,40	60
C		rivestimento effetto spatolato a base di resine	110%	€ 20.839,40	309

Table 1a - Time, cost and quality data for Pilot study
Table 1b - Time, cost and quality data for Pilot study

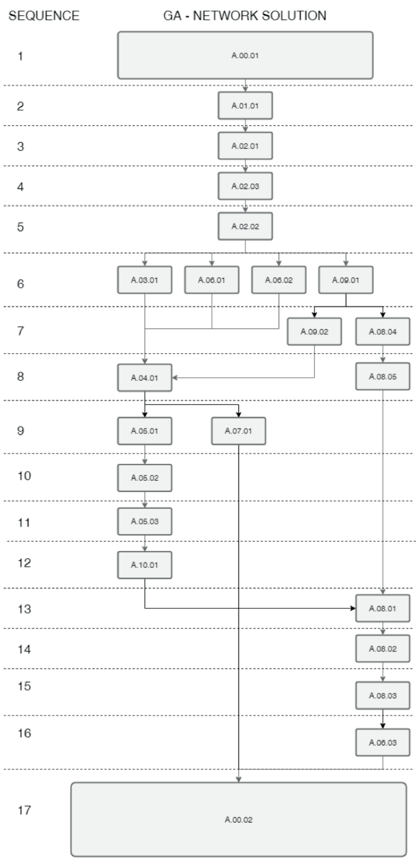
red dots) and the average score of the population improve through generations and asymptotically tend to the fittest score. Identified solutions are consistent through different runs and, if sometimes the fittest genotypes can show slight differences, in most cases the GA solver leads to the same solution. The found results can be displayed with the time-cost-quality chart in Figure 4
As expected, the parametrization of the fitness function strongly affects the solutions offered by the GA tool. In particular, when weighting parameters are set equally for costs, quality and time, the solution presented by the GA shows to be slightly biased towards cost and time, having quality as its worst score (Figure 4 – blue triangle).
On the other hand, forcing the GA to identify the best quality solutions, setting to 1 the quality parameter, 0 the costs, and 0.1 the time parameter, we obtain a quality biased fitness, in which costs and time score worse than in the previous solution (Figure 4 – yellow triangle).
Finally, if the largest weight is given to costs, time and costs are highly maximized (Figure 4 – dark green triangle), while quality score decreases dramatically. The best found optimized result in the case of balanced weights is the following: Total project duration = 1078 (h); Total cost = € 109.711.17; Total quality index = 104%. Further testing of the developed model will be needed to assess its effectiveness in case of more complex projects with multiple environmental constraints.

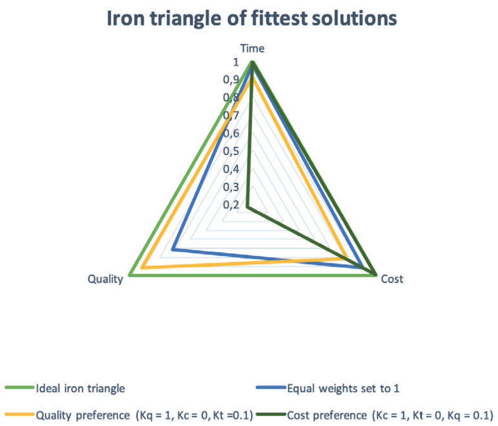
CONCLUSION

The well – known iron triangle of main project objectives, namely time, cost and quality, is still of capital importance for project managers in construction, but balancing these three parameters for actual and complex projects can be difficult because of the unknown or complex function linking all of these three parameters. With the aim of proposing an innovative approach for the time, cost and quality trade-offs, a GA optimization has been developed and implemented with Matlab®. Actual data concerning the

expected duration of each work package, its quality index and its costs are gathered and three possible performing alternatives are detected from an official public works price list.
Therefore, the overall performance of the whole construction project, composed by all the work packages, can be simulated taking into account the different alternatives of activity duration, cost and quality. The overall time estimate can be developed by a CPM- based activity network, the overall cost is the sum of the cost of all work packages, and the overall project quality index can be estimated as the normalized sum of all work package indexes. The aim of the optimization is to find automatically or semi-automatically a balance between these three project indicators by a Genetic Algorithm.
Project modelling for Genetic Algorithm implementation needs a new approach because of Matlab® programming language and coding rules. When developed and implemented, the Genetic Algorithm extracts randomly one work package alternative for all the activities, thus creating a chromosome for each species (i.e. path) of the project for each generation, and compute its suitability by fitness equations. Then, a new generations are created and the found solution in terms of total project duration, total cost and total project quality are compared with the previous one by fitness function computation. The fittest generations are maintained and developed and the others are set aside from the evolutionary process.
The implementation of a Genetic Algorithm needs a new and complex approach in project modelling to reach the final results in terms of fitness of the final generation. Therefore, the creation of the fitness function plays a major role in selecting the developed new generations. Actual data for a pilot study simulation of a building renovation project of two residential apartments has been used to demonstrate the possibility of implementing a GA-based optimization of project objectives, and the found results are consistent with the initial assumptions in terms of ranges of time, cost and quality values. Future research work will be aimed at testing further the developed model with the imposed constraints and with more complex projects.

Total project values	*Maximum limit*	*Minimum limit*
Total project duration	1078 (h)	723 (h)
Total project cost	€ 128.547,49	€ 80.014,53
Total project quality index	109%	95%





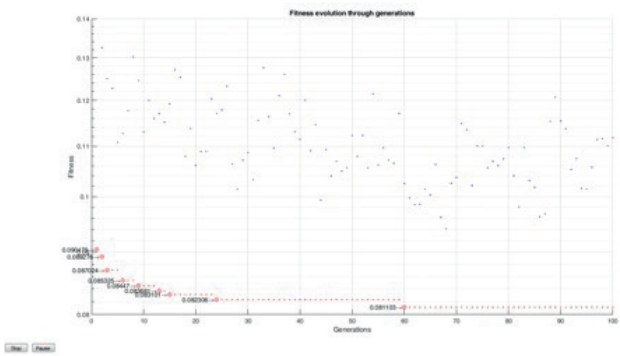


Figure 2 - Network diagramming of the pilot study project.
Table 2 - limit values of total project alternatives
Figure 3 - Fitness evolution through generations. Blue dots represent the average fitness of the population in each generation Red dots represent the fittest individual found across generations. In this specific case, the fittest individual have been found at 60th generation
Figure 4 - Time – cost – quality iron triangle represented with normalized scores. In blue the optimal solution with time, cost and quality parameters equally weighted and set to 1. In yellow, the optimal solution having quality as a preference (quality parameter Kq was set to 1, time parameter Kt to 0.1 and cost Kc to 0). In dark green a solution that strongly optimize costs. In this case, Kc has been set to 1, Kt to 0 and Kq to 0.1

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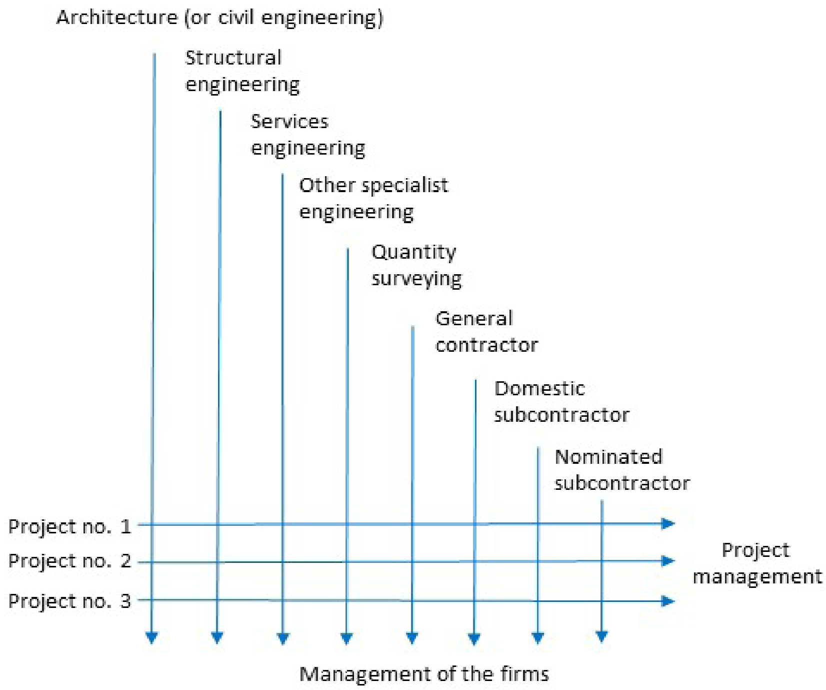
21

Core Project Team As a Management Entity for Construction Projects

KEYWORDS: Core project team, Core team, Construction management, Construction project, Construction teams

The complexity of constructed facilities and the high degree of specialisation in design and construction generates very fragmented working environment for the construction project. Construction project organisations are built up from the units of organisations and they have arranged rules and procedures about how practicalities are to be done. A current perception of construction management is widely built around power, authority, and task orientation. This is resulting from the traditional focus of the construction industry on the technical and managerial features of construction projects. Organisations of construction projects vary substantially in their structure and this structure has considerable consequences to outcomes. Therefore, project management professionals continuously seek and establish new organisational and management structures and linkages to facilitate imperative cooperation between people and project partners. New understanding and amendments are broadening the content of construction project management and have provided new insights for successful construction operations. This paper is based on research according to this continuum by having focus on the appearances of management entity of a new kind, its significance and roles as a part of construction project management. The paper sought to summarize this literature and the survey study by focusing on the project management entity “core project team”, later “core team”. Drawing from this inclusive, the phenomenon of core team, the authors approach the field through six attributes, which have been selected to describe the new way for organising project management.



INTRODUCTION

The construction industry is a project-based industry and they have their traditional ways of structuring projects. When the single firm or organisation perform the project, their challenge is to organise participants from different special fields or functions into an effective project team (Fewings, 2005). When the size of project grows, it is common, that projects are undertaken by an amalgam of independent firms or organisations (Fewings, 2005). According to Walker (2015) the work of company in the construction industry and its specialists present two types of management issues: the problem of managing company and managing projects. The result can be a rather complex management structure. Simplified matrix management structure has been shown in Figure 1.

The matrix is greatly simplified and in practice, this is rarely the case, but this gives a picture on how complex environment building projects are for management. The diagram shows that the same professional practices, general contractor and subcontractors have performed three projects. Usually each project has a different compound of professional practices. This kind of inconsistency makes the improvement the effectiveness of the project management process extremely difficult (Walker, 2015). Traditionally construction project organisations were determined by the arrangements of separated companies selected in competitions. Wide range of organisational arrangements has arisen through the progress of interdisciplinary group professional practices. (Walker, 2015) In addition to this, most activities in the construction industry are organised through temporary organisations, which are designed to provide benefit for a permanent organization or stakeholders through complex problem-solving processes (Söderlund, 2011). Traditionally different stakeholders are solving the challenges of their own field. The experts have been worked independently acting only from their own perspectives, which has caused a fragmented approach to project delivery and reduced project delivery efficiency (Egan, 1998; 2002; Evbuomwan and Anumba, 1998). Complex environment and different goals of stakeholders has placed challenges for management, which have been attempt to solve with different management patters. Project management professionals continuously seek to establish new structures and linkages to facilitate imperative cooperation between people and project partners.

This research focuses on an organisational entity of construction management entitled core team. The aim is to find out how known the core team is, who are involved and how many people belong to the core team. In addition, what a core team does and is it inside one company or is it organised from multi company bases, are under study. Accomplish this, the research uses six selected attributes for exploring the entity.

Figure 1. Simplified matrix management structure (adapted from Walker, 2015)

TEAMS IN CONSTRUCTION PROJECTS

Construction projects are largely unique efforts and their operations can be organised in various ways. The approach to the organisation of construction projects, which are still used in many parts of the world, is an architect as a project manager or leader. With the contractor, an architect is responsible for both design and management of the project based on a competitive tender. (Walker, 2015) In construction business, a project manager has been given practically absolute control over their project. Control is given because a head office does not want to interfere with an operating mode of a project and giving a project manager an excuse to accuse head office interference for failure to active cost and schedule goals. (Oakland and Marasszeky, 2017)

Construction project team as a concept has widely acknowledge practical significance. A simple example of a such team formation can represent the official organization in construction project meaning co-operation between an architect, structural engineer, electric engineer and building system (HVAC) engineer (Kähkönen et al., 2013). Co-operation of these different disciplines is demanded but to reach top quality solutions, smoothly operating team work is required. Informal networks encourage open communication and provide contact both across the function within the team as well outside the team to ancillary functions. According to such an understanding, teams can be formed officially or unofficially and therefore they can be operated officially or unofficially in the organisation.

Moreover we can recognize the presence of various construction project delivery teams and workgroups that can be present during the certain phases of the project. These are usually established formally or informally to serve specific needs such as architectural design, structural engineering, HVAC design, main supplies, site operations etc. Organisational boundaries can create some limits for integrative work but there is aspiration to work in collaborative manner between different teams and workgroups (Baiden et al, 2006). High level integration in construction projects is seen as a key driver of change needed for the industry to be more successful (Fischer et al, 2017). The team design is understood as a core task for integrated project deliveries, which as a whole is highlighting the significance of project teams and team thinking in construction projects (Ashcraft, 2012).

The concept of core team has been interest of authors of this paper. Its presence can be recognized in some text books and articles of practice proposing that there can be some industrial significance around it which also can have impact on the management practices around construction projects. (Kähkönen et al., 2013).

The research behind this paper is on the management of a construction project with the aid of core teams. The research framework is built around six attributes, which present characteristics of core teams (Figure 2). The question behind the research was, does a core team exits? If it does, who are involved and what they do? Therefore, the attributes have been selected to explain awareness of the core team, people involved and how they are organised including their assignments.

'Existence of the core team' scans understanding of construction business professionals o\ver the awareness of core teams. Dothey have knowledge that this kind of management entity has been used? 'Formality' determines the position of core team's relation to the official organisation. 'Professionals involved' relates people involved and 'team size' number of people involved. 'Organising' is related number of companies. Is the core team formed inside a company or are several companies involved? 'Tasks' represent the main assignments of core team.

CURRENT UNDERSTANDING OF CORE TEAM

It has been recognised that project experts tend to use term core team in significance a small group of project executives or experts with a mandate.

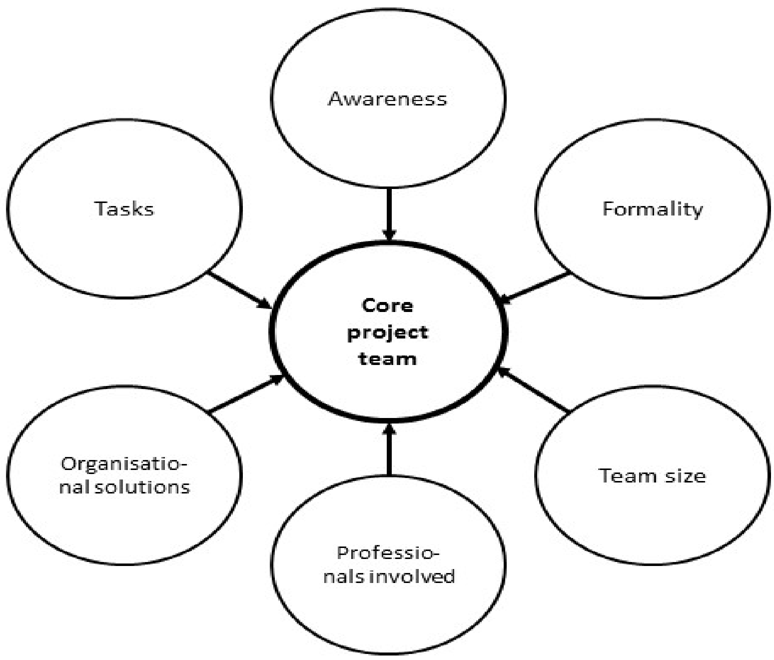


Figure 2. The attributes of the research framework

Despite of being intuitive ad-hoc solutions one should acknowledge them. (Kähkönen et al., 2013) Core team has been mentioned in the project management literature in the context of the construction industry, although only seldom. As a central unit of a project organisation, core team has been mentioned in the project management literature.

Core team is an effective approach to project team organisation developed by PRTM (Pittiglio Rabin Todd & McGrath (management consulting firm)) in mid-1980s in the context of product development (McGrath and Arrow, 2000). Since then the core team has been mentioned in the literature on several fields as a central unit of an organisation e.g. software projects (Carmel, 1995), team knowledge management (Eppler and Sokowski, 2000), organisational approach to technology strategy (Bone and Saxon, 2000), medicine (Haugen et al., 2010), innovation process of the construction sector (Koukkari, 2010), regenerative design and development (Svec, 2012), product realisation (Rihar et al., 2012), new product development (Marion et al., 2012), project management (Wysocki, 2014) and several other fields. Even though the core team has been mentioned in several fields, only a few defines in more details what the core team is.

Hartman (2000) introduces the target organization model in which centre is the core team. These, a small group of people, are involved in a project from inception to completion for its steering and coordination. These people comprise the core team, a subset of the project team. The core team members know the projects and its objectives. They have developed the ideas, set the primary targets for the project and outline the execution plan. Anthony (1992) describes the core team as the circle in the context of product development. It implies equality of the members of the core team. Structure of the core team which Anthony described is shown in figure 3.

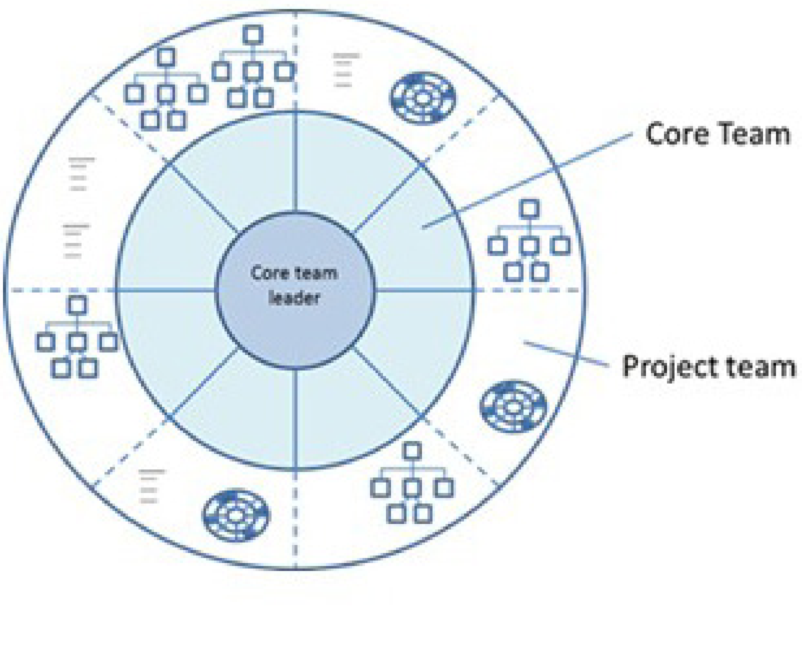


Figure 3. Structure of core team (adaption of picture; Anthony, 1992)

According to Anthony (1992) the core team consists of a core team leader and members of the core team. The role of project team is support and contributes the core team members for their fields. Project teams join in to the project when needed and exit as their work is completed. According to Kaushik (et al. 2014), "The core team governs the project delivery decisions."
Kähkönen (et al. 2013) have recognized that project managers and other project experts tend to use the term core team to mean a special small group of project executives or project experts with a specific mandate and introduced a core projects Team approach in the environment of building construction.

A core team can form in a different way in unequal contexts. Figure 4 presents an example of core team structure where the project manager, the client, the principal engineer, the architect and the BIM-coordinator have formed the core team.
Madusanka and Jayasena (2013) have mentioned core team in the context of integrated project delivery where the owner, the architect and the contactor create the core team. Moore (2002) also acknowledged that large projects may require a hierarchy of integrate project teams where core team is at the top of the hierarchy. According to Kähkönen (et al., 2013), companies generate their own core teams and the strategy of team formulation varies. The core team should be formulated from the professionals so that they would be able to serve the project in the best way. However, it is common that team members in a collaborative construction project should, "be equally committed to a common purpose, goals and a working approach for which they hold themselves mutually accountable" but also "deeply committed to one another's personal growth and success" (Katzenbach and Smith, 1993).
Research methodology and approach
An exploratory research approach was used in order to understand the practical appearances of core teams. Empirical data was obtained by a survey study amongst professionals in the construction sector. The study explores the research topic with different levels of depth starting from the existence of the concept itself and finally looking for the evidence of core teams in real projects. Therefore, first, the research sought to confirm that the core team as a concept could be identified in construction business context.
The survey reached 682 selected manager and director level professionals of construction sector. They were selected from the list of Confederation of Finnish Construction Industries leaving outside small, one-man companies. After data collection period 140 useable responses were obtained. All respondents were over 26 years of age and they were mostly men (92 %). The women's share of the respondents was 8%. The respondents represent the following educational background: grammar school or vocational school (3%), high school (0%), technical college (74 %), and university (22 %). According to this, the vast majority of the respondents, 97%, had third level educational background.
In the survey quantitative and qualitative type of elements of questions were used. Data of qualitative open questions were subjected to a process of which answers were broken into lines, each representing an item that can be captured with a keyword. From this were extracted factors that summarize the data. Summarized data was further grouped into clusters, which were built into categories that form the basis for the theory emerging from the study. Thus, data was treated through several successive reductive phases, it was verified by an independent third party. Independent third party was used to ensure that the data was not being forced into categories, but that the categories represent the data.

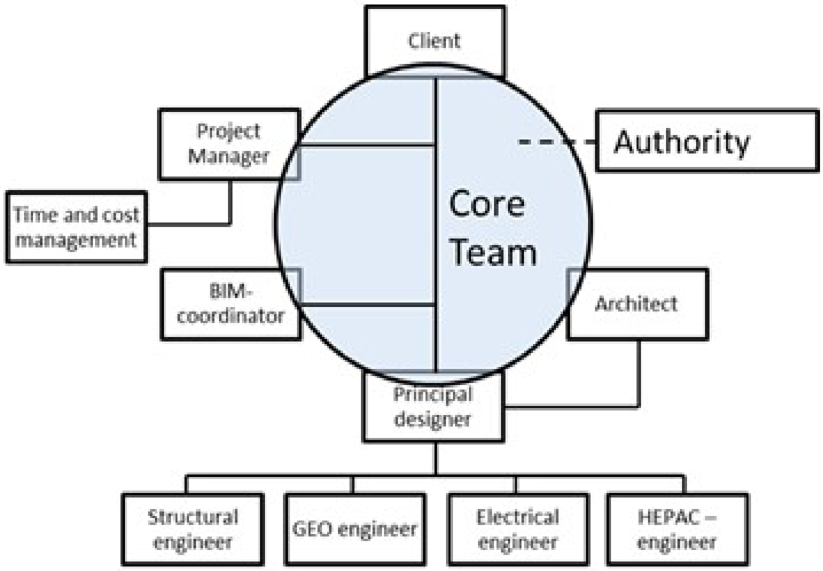


Figure 4. Example of a core team structure

FINDINGS

THE EXISTENCE OF CORE TEAMS

The authors recognized that project managers and experts tend to use the term core team to mean a special small group of project executives or project experts with a specific mandate. In the research, the authors studied the existence of the core team among construction professionals and how widely it is known. Among the respondents, half of them (50 %) have recognized the core team as an organisational arrangement in their construction businesses. They have used or they have known used the core team as an official or unofficial arrangements in their organization.
Question, "did the core team belong to an official or unofficial organization?" measuring a formality. Organization has been defined as an official organization if it has been officially established for the project or it belongs to the official organization chart. Sample items for formality include, "belong official" and "belong unofficial" organization. The total number of respondents was 71. 65 % of the respondents answered that the core team was an official arrangement in their organisation. The rest of respondents (35 %) described that the core team was an unofficial arrangement.

TEAM SIZE

The team size affects the processes of the team. In the study, the authors were interested in the number of the participants forming a core team. For measuring team size, a group of five questions was used. The first question," did the number of people of the core team vary during the project?" Sample items for the question include, "number of people of the core team stays the same" and "number of people of the core team varies during the project". The question divided respondents into two sections.
The first section, the core team was the same size during the whole project, the number of people of the core team were also asked. The amount of respondents to the section was 46 % and the distribution of answers have been presented in Figure 5.

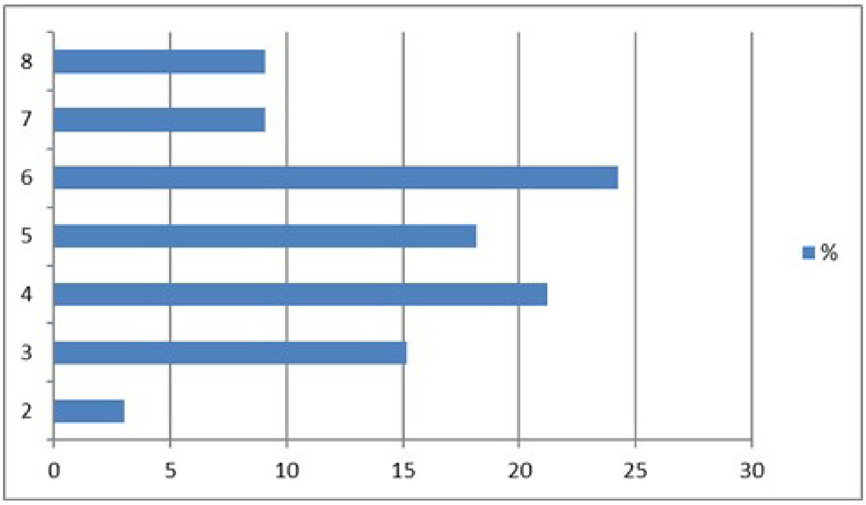


Figure 5. Team size of core team

According to respondents, there were seven different sizes of core teams mentioned. The smallest contained two people and the largest number of people was eight. Most common team sizes seemed to be six, four and five. The median of the answers was {5}.
In section two, where the sizes of the core team vary during the project, the minimum and maximum sizes of the core teams were asked. The amount of respondents to the section was 54 %. The minimum number of people wary between three and twelve. The maximum number of people in the core team vary between three and fifteen.
Organisational solutions
The gained results propose that it is possible to recognize internal core teams or multi-company ones (interorganisational). Most of the respondents have participated the work of core team which was formulated relation with other companies. Based on the survey, 58 % of all core teams are interorganisational and 42 % are internal core teams.
Based on the survey, 66 core teams with different assemblages of members answered and 321 profession were mentioned as participants in the core teams. Professions were grouped into clusters, treated through several successive reductive phase and then verified by a third party. The third party was used to ensure that the professions were not being forced into clusters. The relevant trade clusters that were recognised are construction management, site operations, design, procurement and accounting, supervision and others. Professions such as; safety manager, apartment seller or logistic manager, which were only mentioned a couple of times, were all grouped in the trade cluster 'others'. The grouping of professions was made so that more representatives of the same profession in the same core team were calculated only one. This way distribution of professions in the core teams was determined. Figure 6 shows the occurrence of different trade clusters in relation to the core teams.
Based on the survey at least one member with background in construction management has participated in 85 % of the core teams. At least one member from site operation has been in 76 % of the core teams. The corresponding figure for the members with design background was 23 %. Members from procurement and accounting in the core team were present 30 % from all and the members from supervision 11 %. Individual from other professions has been collected into the trade cluster 'others'. They have at least one representative in the core team in 21 % of all core teams.

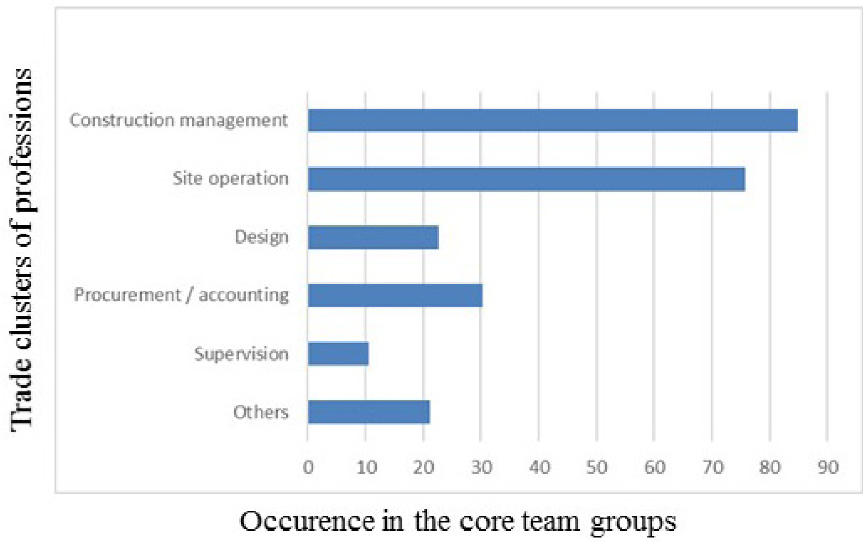


Figure 6. Occurrence of trade clusters in the core teams

TASKS

One of the key interests of the research was to understand the mission of a core team. This was studied with a particular open question. The respondents named the three most important tasks, which have been assigned to the core team in question. The total number of respondents was 65 and each of them named three tasks. The tasks were grouped into clusters, which were treated through several successive reductive phase and then verified by a third party. The independent third party was used to ensure that the data was not being forced into categories, but the categories represent the data. The clusters of task and their share of the total is been presented in Figure 7.
Construction projects are consistently complex maneuvers where multiplicity of duties exist related to the construction processes.
The main attention of management personnel involved is primary on the orchestration of different parties and their activities throughout preparative work, cooperative actions and daily problem solving. Thus, when it was asked what leader or the leaders of a construction project do, the typical answers were: planning, organising, directing and controlling. Concerning a core team, the respondents answered differently. According to the respondents, the main assignment was to take care of the finance of the building project. The schedule control came close to this followed by decision making.

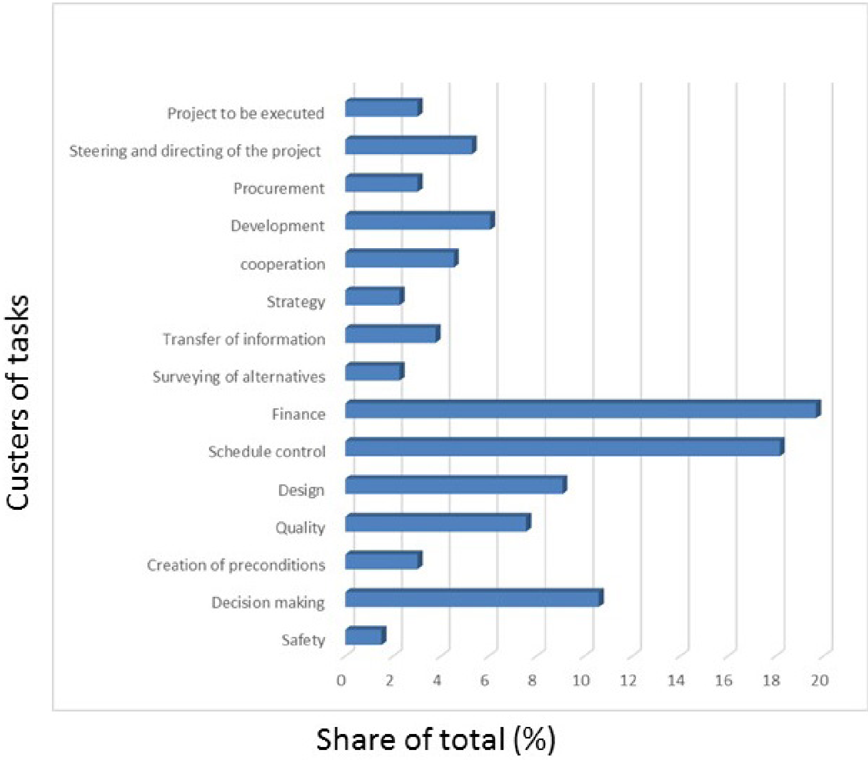


Figure 7. Main tasks of a core team

DISCUSSION

The construction industry can be characterized as a complex project-based industry where the operations are frequently structured in traditional ways. Too often, vital decision making is drowned by a hierarchical manner where part optimisation procedures are hindering the achievement of high-value results (Kähkönen et al., 2013). In construction business, a project manager has almost full control over their project (Oakland and Marasszeky, 2017). Albeit, in construction projects the high-level integration is seen as a key driver of change needed the industry to be more successful (Fischer et al, 2017). Fragmentation is the consequence of two major factors (Mitropoulos and Tatum, 2000): the high specialisation in design and construction and the intricacy of the constructed facilities. Specialisation is the consequences of distribution of work between organizations as well as between organizational positions. Specialisation permits an organization gain greater degrees of know-how among members but consequences might be the fragmentation of knowledge and different objectives. The danger is that experts do not understand the consequences of their decisions from the point of view of other stakeholders of the production system. The result is part-optimum decision which is it is not the best for the whole project. Likely, conflicts will exist among participants. A core team is an optional organisational settlement for managing construction project teams.

Often construction project organisations were settled by the arrangements of independent companies selected in competitions. A wide range of organisational arrangements has arisen through the progress of interdisciplinary group professional practices. (Walker, 2015) Traditionally, stakeholders are solving the challenges of their own field and the experts have been acted only with their own perspectives, which has reduced project delivery efficiency (Egan, 1998; 2002; Evbuomwan and Anumba, 1998). Therefore, new organisational structures and linkages are sought to facilitate imperative cooperation between stakeholders.

The team design is understood as a core task for integrated project deliveries, which as a whole is highlighting the significance of project teams and team thinking in construction projects (Ashcraft, 2012). Design and production strategies and partnering arrangements have been used to attempt to integrate the construction project delivery team (Love, 1998; Anunba et. al, 2002). However, many of these well intentioned attempts have not fully achieved to anticipated success probably because they are frequently superimposed onto environments where adversarial cultures and attitudes still exist (Moore and Dainty, 1999, 2001).

Perhaps the organisational approach, where management of separated teams of stakeholder is integrated more closely, provides more value adding collaboration between project partners.

The core team is an interesting management arrangement in construction business. It seems that core teams as an approach are particularly used in complex major projects where the core team can bring together the key players with a sufficient mandate to steer the project further. Among the core team members the responsibilities are shared and the team can be responsible for the overall success of the project.

In decision-making, part optimisation is avoided and decisions are made based on what is the best from the point of view of the whole project. Companies selected their own core teams and there are several possible way to formulate the core team. Construction projects have all their own unique features and each core team seems to be formed according to a project.

The core team is established for the project, thus tackle the management issue presented by Walker (2015): the problem of managing company and of managing a project.

CONCLUSIONS

A typical construction project is an effort that involves a number of different organisations brought together. The challenge is to organise the participants of different organisations, special fields and functions into a form of an effective project team. This paper focused on describing the role of core team. To do this, the research used six attributes for exploring the entity.

The research findings show that the concept core team has been recognised in several fields, whereas only a few examples were found with a detailed definition of core team. Additionally it was found that the core teams could exist both in an official or unofficial organisational arrangements in construction projects. It seems that the official arrangements are a somewhat more frequently used approach. The number of members in a core team can be fixed during the project. Based on research almost the half of teams reported being like this. Usually a project core team is composed of six members. Based on what types of skills are needed in the different stages of projects, the number of members can vary during the project. The core team can be organised inside one company, but it seems, that organizing the core team interorganisational are a somewhat more frequently used approach. Over 300 professions were mentioned belonging to the core team. It was found that construction management and site operations were the most represented clusters of professions that had at least one member in the core team. During a construction project, the tasks of the core team are multifarious. The research findings show us that three main tasks of the core team are taking care of the finance, schedule control and make decisions.

We see the core team as an important development of project structuring that does not hold a fully developed position as a part of formal project structures it can have. In the future, the manning, mandates, contractual recognitions, established approached and decision-making practices are the dimensions where developments should take place. This kind of new team concept can be useful for taking the full benefits of project teams as project structuring approaches.

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