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Constructability and Safety Assessment Design Approach
Verifica di costruibilità in sicurezza con l'ausilio di strumenti grafici

The theme of this contribution fits astride two strands of the studies of Construction Management: health and safety risks management on construction sites and constructability design approaches. The hypothesis developed in this approach is to entrust the design a harmonizing function between the parties. In particular, it refers to the delicate moment in which Executive Design implements in a Constructive one. The method proposed, working directly on design drawings, allows the specific and detailed assessment of safety conditions for the realization of the item in question. This allows, as well, to verify the constructability of the element itself, before opening the working site and when it's still possible to intervene, if necessary, with amendments under the designer control.

Il tema del presente contributo si inserisce a cavallo di due filoni di studi propri del Construction Management: la Sicurezza Cantieri e la Costruibilità. Per affrontare la questione si fa riferimento ad un approccio che riconosce un ruolo chiave all'attività progettuale in generale ed, in particolare, alla evoluzione del Progetto Esecutivo in Costruttivo. Il metodo proposto consente, intervenendo sulla rappresentazione grafica degli elaborati progettuali, da una parte la valutazione specifica e dettagliata delle condizioni di sicurezza per la realizzazione dell'elemento in oggetto, e contestualmente di verificarne le condizioni di cantierabilità, in una fase precedente il cantiere e quindi in un momento in cui è ancora possibile intervenire, se del caso, con modifiche, più o meno significative sul progetto senza che esso ne risulti snaturato nella sua primitiva impostazione.

Keywords*:* construction management; constructability; health and safety; construction site; executive design

Parole chiave*: construction management; costruibilità; sicurezza; cantiere; progetto esecutivo*

The goal of improving building process for better construction results can be usefully implemented investigating possible relationships between health and safety risks management on construction sites and *constructability* design approaches.
The issue of safety is strictly related to construction management for the use of provisional facilities, of equipment and machinery, of hazardous materials and for poor environmental conditions, but above all for the need to work "at altitude". The unpleasant result is that workers of Construction Industry have in many countries the sad distinction of being at the top for numbers of deaths at work. This is an old problem, because is intimately connected with the dynamics of construction phase, but only from some twenty years it has particularly felt as social emergency, for a raising awareness of public opinion and probably as a result of a specific focus of international and local legislations. Remains an item worthy of note the progressive decrease of the incidents as a consequence of amendments to the legislative apparatus precisely, paradoxically, when the growing media attention leads to the general public feeling that is growing the number of accidents.
Who is involved for work or research in Construction Management or Building Production, must be interested on the question, because significant for the entrepreneurial dynamics in the construction industries. It's wrong to believe this is only a boring and probably useless issue of formal compliance. Regarding safety duties small companies complain often about a lack of actual improvement in the cost-benefits balance compared with the high price paid in terms of heavy bureaucratic apparatus characterized with a strong impact in terms of time commitment, utilization of human resources and economic investment. For sure this is a long-term investment and now we are paying also a generational price in terms of workforce accustomed to work under insufficient safety conditions. Surely the oldest ones may have suffered the invitation to change their *way of working* as an external coercion, often incomprehensible, for formal requirements which are justified by the risk of a penalty, more than by necessity. Even worse is the widespread feeling that the *Safety* could even be an obstacle to work.
Although all the efforts, the number of accidents is dramatically high and who is deputed to safety audits or to statistical reports presents the issue again in terms of emergency.
Laws improvement cannot be regarded as the only way to improve the situation, although necessary to file down aspects not congruent with operational dynamics. Also because, statistically countries with similar or comparable legislative systems, (e.g. Italy-Sweden), have on the other hand, significant discrepancies on the number of accidents. Marker element that are other parameters to influence in terms of risk prevention. Surely these differences are justified for a longer experience of *best practices*, as well as for having started risk prevention education before being request by European Directives. It's important to notice that best practice are typical of systems that favor big companies, compared to small ones, traditionally more in difficulty in the attempt to respect the formalities required by law. In social and anthropological terms, the different way of perceiving risk and need for protection should deserve a specific analysis, according to different countries and cultures.
All of these reasons give the sense of the complexity of the issue, but do not help to get out of the impasse of considering the safety as something "in addition". An extra difficulty that complicates a sector hits by a devastating crisis that should require more slender procedures than complicated algorithms. The recent Italian law L69/2013 is fortunately a signal toward the safety of "substance".
On the other hand, who does safety audits still complains for quality of safety documents, because their lack of specificity, make them insufficient in order to be effective, helpful in transmission and shared with those who work in construction site.
The general problem is to have a specific, relevant, effective assessment which isn't a hindrance to the construction process. Instances and requirements, by contrast, often disregarded in a practice that sees the moments of the construction and safety of workers at best separated, if not opposite, but almost never concurrent and integrated.

The hypothesis developed in the approach of this contribution, is to entrust to the design a harmonizing function between the parties. In particular, it refers to the delicate moment in which the Engineering Design becomes Construction Design. The idea is to insert the "safety assessment in construction phase" as useful parameter for project improvement in order to achieve a building quality.
The issue of relationship *building-project* is another old matter too.
Considering that project is the passage from the moment of foreshadowing of the artifact, its virtual simulation, the definition of dimensional features, techniques and technologies, at the time of actual implementation, this means that it is inevitably a solution of continuity. From the private moment of design office, you need to move yourself to the *agora* of the construction site. There the multitude of the subjects and the correlation between physical and environmental factors, goes to edit a system codified by tools of representation, computation and scheduling of the intervention. In other words, during design phase there is the possibility of managing the control of process with a uniformity that coincides with the designer willingness in a synthesis between intentions and proposal
The issue has been addressed by scholars of Construction Management for a long time, under the name of *Constructability*. Actually in English exist two similar words: *Buildability and Constructability*. The two terms are considered by some researchers as synonymous, but according with others there is a different shade of meaning. Buildability, therefore, refers the specific relationship between the project and the construction management, while *Constructability*, refers to the relationship between design and realization in the context of the entire Building Process.
This is a broad area of study in the field of technology of construction involving many researchers, and several *Buildability* definitions have been proposed by researchers and organizations. The widely accepted definition is that of the Construction Industry Research and Information Association (CIRIA), which states that "*Buildability is the extent to which the design of a building facilitates ease of construction, subject to the overall requirements for the completed building*".
Many research contributions help, underlining various shades of meaning, to complete and clarify the theoretic implications:

- Illingworth (1984) defines buildability as the "*Design and detailing which recognize the assembly process in achieving the desired result safely and at least cost to the client*".
- This definition has been modified by Moore (1996) as a "*Design philosophy, which recognizes and addresses the problems of the assembly process in achieving the construction of the design product, both safely and without resort to standardization or project level simplification*".
- Ferguson (1989) refers to the Buildability as the "*The ability to construct a building efficiently, economically and to agreed quality levels from its constituent materials, components and sub-assemblies*".
- Chen.et al., 1991 defines buildability as "*the extent to which decisions are made during the whole building procurement process, in response to factors influencing the project and other project goals, ultimately facilitating the ease of construction and the quality of the completed project*".
- According to Low and Abeyegoonasekera (2001) "*Buildability is related to all aspects of a project which enable the optimum utilization of construction resources. It ensures that there is continuity of work by managing labor, plant and equipment in such a manner that the flow of materials, components and sub-assemblies into the growing building is maintained and optimized to achieve efficient and economic production. It is concerned with activities on site and specifically with the logical sequence of operations and construction methods*".

It is possible to highlight how all definitions of *Buildability* share three main points :

- The function of the project to facilitate the construction.
- The holistic view of the project.
- Any principle or philosophy on *Constructability* must fit within a set of General requirements

to give completeness to the building.

In synthesis we can define *Buildability* as the extent to which the project of a building facilitates the efficient use of technical resources, improves the ease of construction, construction safety, getting the project triangle (time, cost, quality) while customer requirements are satisfied.

In cases where it is not considered to be a synonym of *Buildability*, *Constructability* has been defined in various ways. The most accepted notion is that developed by the Task Force on *Constructability* of CII that defines it in (1986) as "*the optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives*".

Another important definition has been provided by Construction Industry Institute Australian (CII Australia, 1996) "*The integration of construction knowledge in the project delivery process and balancing the various project and environmental constraints to achieve the project goals and building performance at an optimum level*".

Later the same Institute has updated this statement (CIIA, Griffith and Sidwell, 1997) as "A system for achieving optimum integration of construction knowledge in the building process and balancing the various project and environmental constraints to achieve maximization of project goals and building performance".

More specifically, Lueprasert (1996) defined *constructability* as "*An important feature of a structural design and the construction project site conditions, which determines the level of complexity of executing the associated structural assembly tasks*".

The construction Subcommittee of the AASHTO (American Association of State Highway and Transportation Officials) defines *Constructability* review as "A process that utilizes construction personnel with extensive construction knowledge early in the design stages of projects to ensure that the projects are buildable, while also being cost-effective, biddable, and maintainable" (*Constructability* Review Best Practices Guide, 2000).

As mentioned before, the *Buildability* and *Constructability* terms are commonly used interchangeably, and many researchers believe that there is no difference between the two concepts, except that *Buildability* is usually used in the United Kingdom, and *Constructability*, is often used in the United States.

Anyway, the possible difference of meaning can be so expressed:

- *Buildability* refers to the extent to which a building project facilitates ease of construction and in the meanwhile are met the client's requirements. It focuses on the design of a building;
- *Constructability*, embracing the functions of management and design, covers a broader scope than the *buildability*. Interacts with project management systems that use optimally the knowledge and experience of the construction to improve the effective attainment of the objectives of the project.

We can express in the simplest way by saying that:

- *Buildability* is a concept strictly related at the project
- *Constructability* deals with the design process in a wider sense involving the whole building process

Analyzing the results of British studies in the last fifty years, it' possible to summarize the causes of *constructability* problems in the fragmentation of industrial production (Banwell, 1964), the lack of effectiveness of design because of construction poor knowledge of designers and lack of inputs of contractors. Gray (1983) and Griffith (1984) suggest to underline the importance of constructive skills of design, by adding contractual constraints aimed to improve *Constructability*.

In these theories project has a key-function, being considered as a platform to optimize, according to its function, more effectively within the Construction Process.

Talk of "Optimization" is always a perilous field, because should be defined parameters and references necessary to assess the actual improvement of the instrument concerned. The safest route is that

of direct experimentation on the spill-over effect in terms of improving the "easy construct". The underlying question remains: "on what elements forming the project we can intervene in order to enhance its effectiveness in the construction site?". The answer, according with research approach here presented, is twofold: the contents and the representation thereof.
The two aspects are of course intimately related: representation is nothing more than a clarification, communication transposition, objective display of content, which in their textual expression may be not clear.
But the representation is much more, as it allows to contextualize the content, especially in terms of requirements and performance, and make them congruent with the specific artifact in a technological and geometrical adjustment to the specific product to build and to the specific environment in which it is inserted.
This consideration of visualization and congruence, has come up with the idea at the basis of this contribution.
The relationship between project and construction sites, such as the theories of *Constructability*, obviously has already fueled a series of international research strands.
For Griffith and Sidwell (1995), many problems of inadequate design and production methods are related above all to unclear or missing project information, and general lack of co-ordination between design and construction.
If the graphical representation is not only "passive" image of content, but it is its " active" check in terms of specificity and consistency, being mirror and simulation of built result, why not try to improve the contents going backwards to the analysis of representation? And yet, why not accentuate the "dynamism" implied in the project whose representation is usually based on "static" sections of the final result?
Therefore, the operative idea of this approach is to re-elaborate project drawings to clearly express those construction processes implied in the representation of "result". The representation of the "finished", has a fundamental problem: the graphic perfection, dangerously close to "art work", although aware of the technological evolution in terms of performance, requires a logical consequence in his design scheme. A construction sequence to demonstrate the effective compliance with the requirements of the construction site in general and the specific choice of possible production.
Starting from the representation of construction details it is possible to simulate the construction of them. This is possible through progressive drawings that express the breakdown in construction phases, processed chronologically and logically related. In these specific drawings are placed graphically those elements of the site (temporary works, machinery and manpower) that allow you to view, and then verify the conditions under which it is assumed it will be the realization of every single element that contributes to the final result express by the accomplished detail.
The procedure allows the specific and detailed assessment of safety conditions for the realization of the item in question, and verify the *constructability* of the element itself. That's important because this happen before construction stage and at a time when it is still possible to intervene, where appropriate, with amendments, more or less significant on the project itself. Above all this is a moment in which the designer can still have the whole control over project otherwise what happen when is the construction management to impose those changes that end up affecting the formal and technological result, without the possibility of a final assessment of its congruence with initial settings.
In methodological terms, the procedure involves a preliminary choice of the building details (fig. 1) considered relevant for their difficulty of realization or their repetitiveness in the entire structure. Every single detail is examined as provided in executive (engineering) design and analyzed according to constructability parameters following a logical pattern like this:

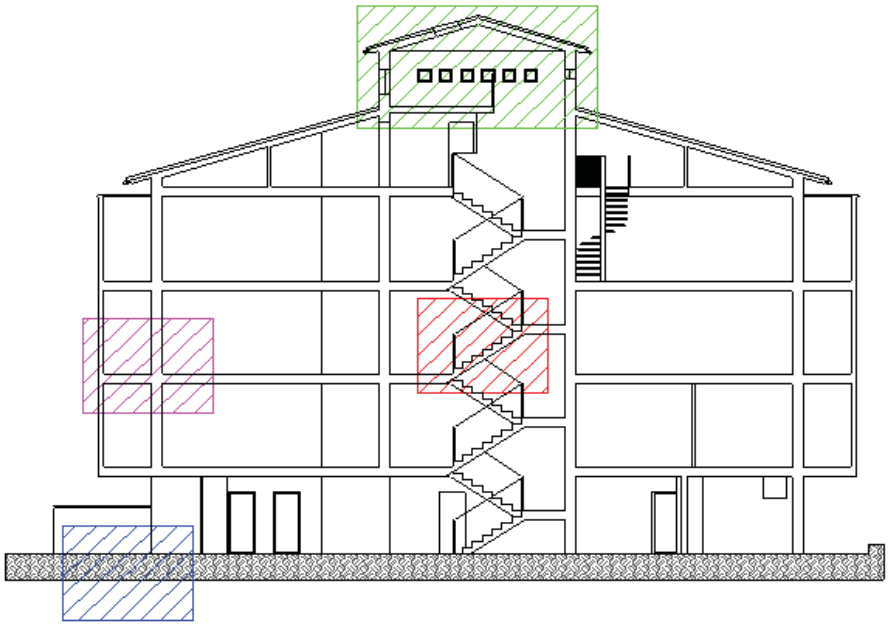

Figure 1

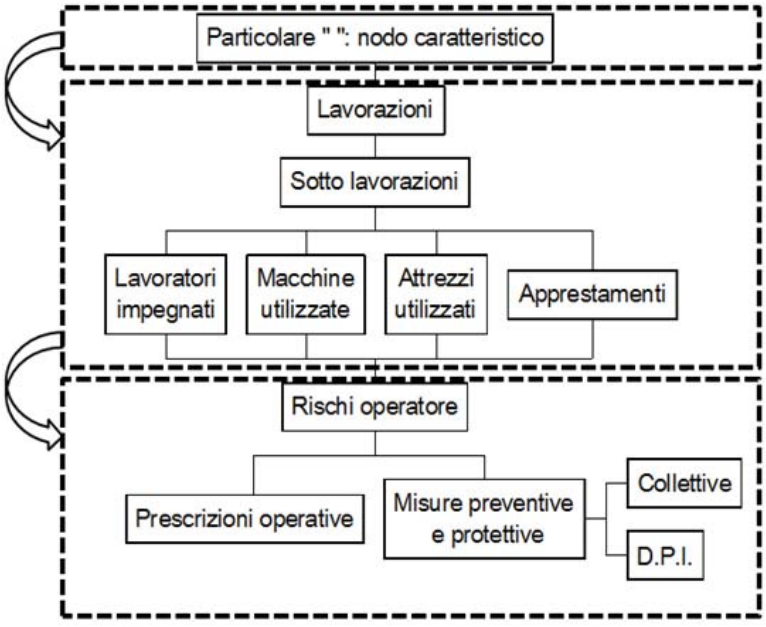

Figure 2

In terms of graphical representation teaching purposes, but in view of a likely professional application, it's been used a sheet A3 format with a view to greater handling in the construction site. The sheet is broken down into three main areas (fig. 3), which can have a graphical composition freely chosen by the compiler, but with a strict sequential logic concatenation according to the diagram:

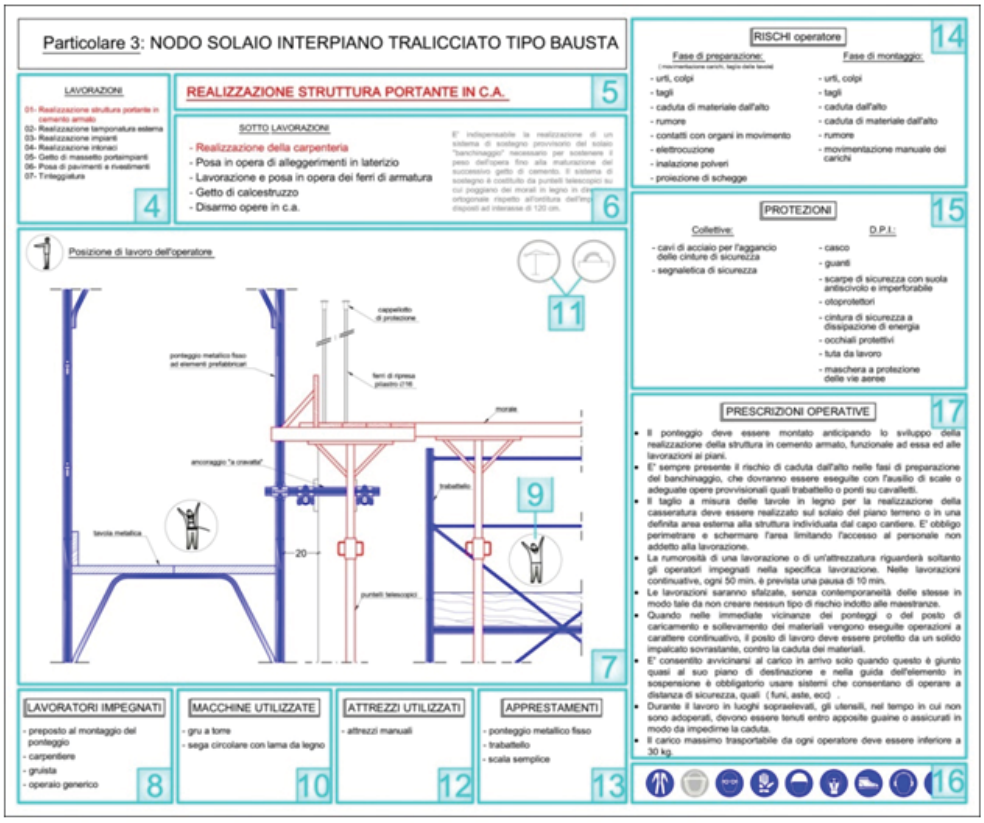

Figure 3

1) *Graphical representation of construction detail and of the specific working phase to be realized*. This must be the main part within the table. In terms of communication should immediately be clear what you are referring to and, compared to a traditional detail, it provides a range of information related to construction needs such as the position of operators, the presence of temporary structures, the presence of machinery. To this aim it may be useful to integrate the details with diagrams and maps section to clearly putting them into context within the building, or possibly with photographs in case you are in the presence of a conversion of an existing building. It is essential to draw temporary structures with their real dimension, because this allow to analyze if there is physically and volumetrically an interaction and interference with the building structure under construction. The need of commitment of specific workers and machines can be, vice versa, schematized with symbols in the form of dimensionless logo. Graphically it is characterized also by a didactic use of color: "black" for the already built part, "red" for the parts realized just during the analyzed construction phase, "blue" for scaffoldings, "green" for temporary structural support works. The dynamic variation of colors from a table to another expresses the evolution of construction;
2) *Description of work phase parsed with the specification of the type of labour and of features, equipment and machinery required*. It is complementary to the first part that integrates with explicit information on the specific work phase of the construction site;
3) *Risks assessment and identification of individual and collective prevention measures*. It is the part that shows the data analysis introduced in the first two parts through the graphical presentation. This allows to highlight constructive criticalities both in terms of building procedures and in terms

of safety of workers, especially related to interactions human-computer, man-man, provisional structure-structure.

It was made an attempt to assimilate this process to some of the safety planning tools required by European legislation in general and by the Italian one in particular. At the beginning of this research the closer it seemed the Safety and Coordination Plan (PSC), and in experimental applications of recent years it has been used the definition of graphic-PSC to synthetically express this approach and actually it can be useful to deepen specific problematic aspects of this risk assessment document. But trying to find a direct correspondence with an official document requested by law, this can generate confusion on its actual value. It's more appropriate to consider it as a general *Constructability and Safety Assessment design approach*, that can be used occasionally to deepen specific problem of risk assessment, but above all as a validation procedure of the correspondence of a design to the construction sites requirements.

Talking of further improvements, the most natural development of this "graphic" approach is to find a more structured evolution in BIM strategies, but right now there are still problems to use informatics in an interactive way and not only as CAD tool to improve this design method.