Conceptual Structural Design: an important topic in architectural education

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ABSTRACT: This paper is based on a project developed within the 2012 Architecture and Construction Design Studio at Architecture of Building School, Politecnico di Milano. A project for a new railway station in Milan was the design topic. This paper resumes the early conceptual design stage. Considering architecture, structure and landscape, several design proposals are investigated. Jointly with Mathematical Models in Architecture and Numerical Analysis Studio, Structural analysis were performed by ADINA900. It proved to be an optimal and educational software tool for efficiently evaluating structural design decisions over the ordinary practice.

1 INTRODUCTION

Over the last decade, structural design has become much more complex. New topics have been involved in the design practice, lending support to minimize structural cost. Thus, design becomes an interdisciplinary process, where the main disciplines concerned with work together in conceiving and realizing the building.

Actually ensuring a required service life of a new building is the main aim. Materials cannot guarantee a high performance over an unlimited time (Malerba et al. 2011). Since steel, timber and concrete as well as any biological system suffer from a time-dependent deterioration process, they need for maintenance. Whenever maintenance has been considered and evaluated from the very beginning of the design's decision-making process (Garavaglia et al. 2012, Basso et al. 2012), the whole cost of the building (initial and maintenance costs) may be reduced.

Since incidents and terrorist attacks may seriously damage Lifeline systems, extraordinary loads typology has just been added to regulations. Structural response to critical risks, such as fire and explosion, has to be carefully evaluated and managed (Gentili et al. 2010, Giuliani et al. 2012). When an emergency occurs, critical facilities (e.g Lifelines, Emergency Shelters, Medical Centres, Major Industrial and Commercial Centres, etc.) must be efficient.

Therefore mainly structure robustness has to be investigated. Comparing with initial damage, ongoing failures have to be avoided (Giuliani et al. 2007, Giuliani & Prisco, 2008). Basing on disastrous collapses occurred during recent earthquakes, technical details design should be reviewed and improved (Sgambi et al. 2011).

Increasing design process complexity, designers need for new advanced supports in order to arrange and analyse data. (Bontempi et al. 2005, Arangio 2005, Sgambi et al. 2005). Since the very beginning of the design process (Conceptual Design Phase), structures should be considered as a relevant cog in the design machinery, providing an effective and performing solution. Conceptual Design is an interdisciplinary phase. Over the last decades, several studies have been made on data arrangement (Austin et al. 2001, Chakrabarti & Bligh, 2001), problem-solving strategies (Bontempi et al. 2004, Liikkanen & Perttula 2009, Arangio & Bontempi 2010), uncertainties and approximations management (Sgambi 2004, Sgambi 2005, Dordoni et al. 2010), support tools for team working (Fuyama et al. 1997, Fenves et al. 2000, Wang et al. 2001, Anderson et al. 2003).

There are at least two unresolved issues.
Considering tools already developed and mentioned in scientific literature, they mainly refer to monodisciplinary approach. That points out the need for switching over to an interdisciplinary scale. Thus, decisions and tools developed within Conceptual Design phase may be generally applied to Design phase, where several and very different disciplines are involved in. Actually Conceptual Design is the most relevant design process phase. Hence, since the very beginning of their educational career, the-designers-to-be should hardly and carefully train Conceptual Design phase and concur in making it multidisciplinary.

2 DESIGN PROCESS

2.1 *Design space*

Design is a creative process and it doesn't follow a linear path. The *design space* is a Cartesian coordinate system where design process takes place (Arielli, 2003). There are three axes: concreteness, completeness and variants. Concreteness is the accuracy of the project. At first just two lines represent a two-dimensional wall frame (low concreteness). Finally the wall will be defined by its materials (i.e. elements and thickness), load capacity, thermal properties, and surface finishes (high concreteness). Completeness is the extension of the project. Referring to a campus, design process will probably start from classroom system, while sport facilities will be considered later on.
Although final design is clearly defined by high concreteness and completeness, design space needs for a variants-coordinate due to non-linear nature of the design process. When variants are included, the designer's experience ma be taken into account and the complexity of the problem may be effectively managed. Thus different design approaches and proposals may be investigated.

2.2 *Design approaches*

Usual design methods are divided into two approaches: top-down and bottom-up. The former one is a conceptual approach and it considers design process mainly from the general composition view. First of all completeness is investigated and comprehensively defined. When the requested/desired completeness has been achieved, concreteness will be approached and other disciplines (i.e. structural design, technical details design and plumbing design, etc.) will be included within the design process. When the interdisciplinary contribution has been postponed, the whole design process might be unsuccessful or rejected. Designer is faced with a double choice: a passive confirmation of decisions made by others disciplines; otherwise starting from a close-to-the-beginning condition, a new design method may be approached. The design practice should be repeated till any interdisciplinary request has been satisfied. That's the main method which architectural students are used to perform.
The bottom-up is a heuristic approach where the inductive reasoning has been generated directly from the requirements set up by the designer himself (e.g. a 5x5-metres structural mesh). Thus concreteness has been firstly and mainly considered. Since a high concreteness characterizes design solutions, few problems will be encountered in advanced design process. The main weakness in performing a bottom-up approach is that narrow design solutions have been provided due to strictly bound reasoning. Whenever a designer realized any topic impossible to be solved through preset rules, he should go back to close-to-initial-state conditions. He should modify initial concreteness assertions and repeated the reasoning. Once again that is usually practiced among architectural students.
Top-down and bottom-up are both serial processes. In practice, solving a series of multidisciplinary design problems, they achieve a certain design solution. Whenever an impossible-to-solve problem occurs, design process fails and a new one must start. Both the abovementioned processes cause a great waste of energy and discouragement due to a low-quality scientific approach to the complex design problem-solving. Those serial approaches seem to oversimplify the design process to a trial-and-error strategy.

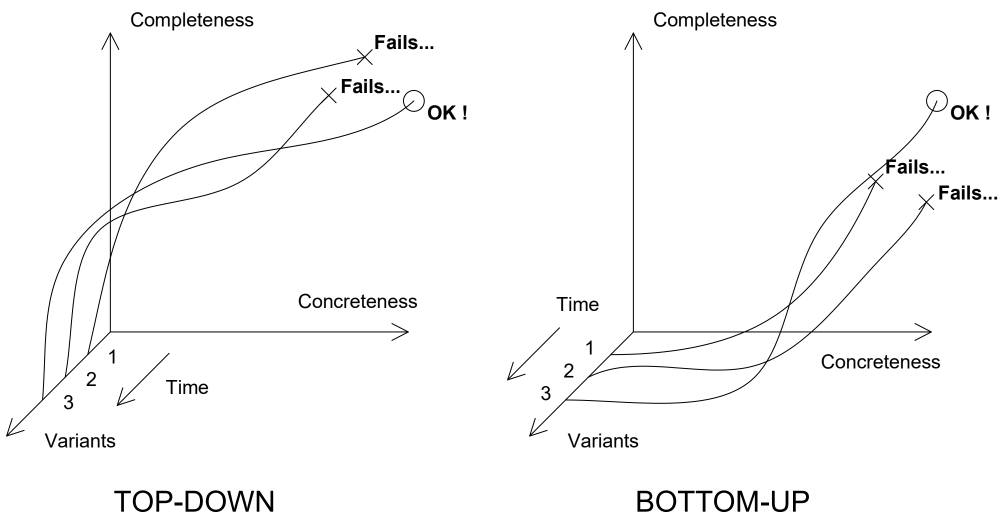

Figure 1. Serial Design Approaches: top-down design (left side) and bottom-up design (right side).

Actually architectural design is a logical and creative multidisciplinary process. Since nowadays buildings are designed to exceed disciplinary boundaries, any serial approach cannot match design expectations. Thence a brainstorming technique is more effective in generating complex design involving a huge multidisciplinary system. Before completeness and concreteness are considered, design solutions have to be multidisciplinary discussed. The most effective proposals are deepened until the final design solution is achieved. Such a different approach, called emerging design, avoids premature design decisions, which mislead designers. Since design variants work in parallel, they open up a vast array of competing solutions. A parallel between emerging design approach and Darwin's theory of "survival of the fittest" clearly comes out. Considering an initial population of design variants selected by a multidisciplinary brainstorming, weak proposals are gradually dismissed, leaving only the fittest solutions. Although weak proposals have been given up, some of their design properties might be included within the optimal solution by mutating or exchanging genetic operators (i.e. crossover process). After an appropriate period of time, the final design solution comes out.

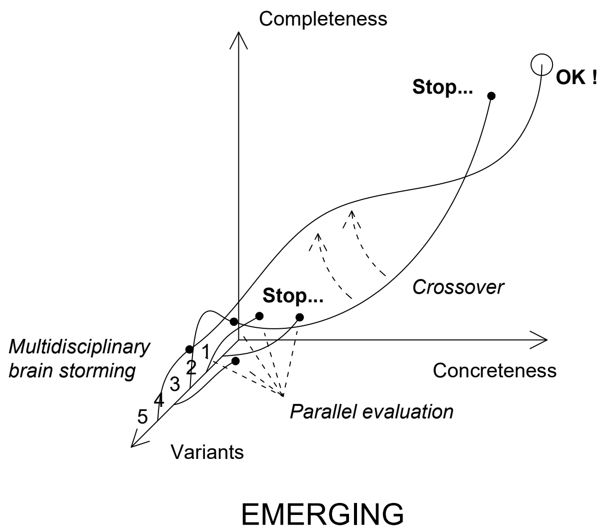

Figure 2. Parallel Design Approach: emerging design.

A set of multidisciplinary requirements has to be defined and applied to each solution within the population of design variants. That's the key point of the decision making process. Questions have to be specific and concern just one topic. Evaluating design solutions' answers, a fairly objective judgment may be obtained leading to select the fittest proposals. The abovementioned approach will be deeply analysed in the following paragraph, where emerging design has been applied to a project developed within the 2012 Architecture and Construction Design Studio (Professor Giulio Barazzetta).

3 PRACTICE

A project for the new railway station of San Cristoforo in Milan (Italy) was the design topic for the 2011/2012 academic year. It's an important transport interchange due to its crucial position right at the joint of main infrastructural networks (i.e. roads, railways and subways).
De Magistris described the San Cristoforo station as an industrial and public building, in between a city monument typical of hieratic architecture and a manufacture typical of the technological era.
Basing on De Magistris' thought, the new railway station's project has been developed: a complex system including a railway station, a subway station, a tram station an interchange parking for car, public transport and small boats for sailing the Naviglio (the man-made inner canal network in Milan). It should become a symbol of both urban renewal and technical era. The Nineteenth-century approach based on volumes juxtaposition (i.e. neoclassical façades and large steel-and-glass vault) was avoided. Conjunction of architecture and engineering has been achieved through a balanced solution based on the correspondence between machine and station. On an urban scale the building represents the city's identity due to its relevant size. Considering an architectural scale, the steel shell of the building treasures a complex system where the interaction between structural and non-structural elements (i.e. béton brut -structural- and steel -suspended floor system-) takes place. Basing on Rem Koolhaas approach, since the building is an infrastructural interchange, it should be "leant" on the ground without any urban influence. Thus shall has no hierarchical orientation, it just protects the floors vertically lined up and connecting different infrastructures. Both the empty hole in the middle and the elementary shape ensure fast and easy inner connections. Since there isn't a main axis, continuity in space has been proposed.

3.1 Defining design variants

Basing on preliminary considerations, a cylindrical shape has been preferred. Referring to the structure, four proposals have been investigated (Figure 3). Structure 1 is a façade system reminding the gasometers built up towards the end of the 1800's and still surviving as urban monuments of Milan. Structure 2 has got three stairwells supporting two round reinforced concrete plates. Structure 3 has got a column system in addiction. In structure 4 the suspended roof system has been designed to receive all vertical loads. Then a pre-stressed reinforced concrete beam system on the roof shares loads between the three stairwells.

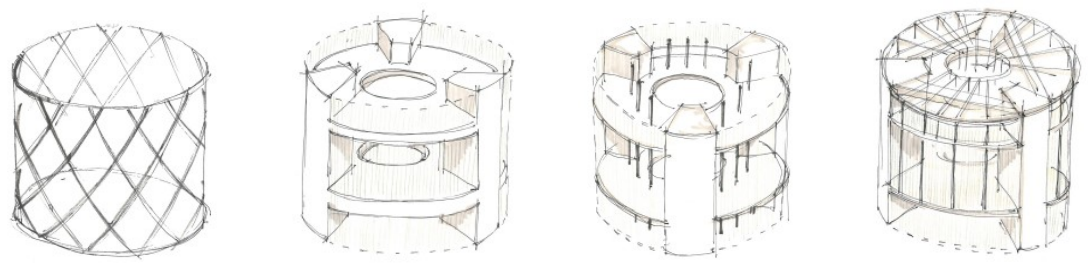

Figure 1. Four design proposals for the new San Cristoforo's railway station.

3.2 Questioning and problem solving

Any design proposal should answer to some questions in order to be evaluated. Those questions have been divided into four disciplinary categories (i.e. composition, structure, technical details, plumbing system). Since this paper deals with Conceptual Structural Design, all questions start with “Is the structure suitable for etc.”.

COMPOSITION:
Is the structure suitable for ensuring spatial continuity at the ground? (1)
… being a city landmark? (2)
… ensuring an easy-to-compose inner spaces? (3)
… joining other support facilities by connection holes? (4)

STRUCTURE:
Is the structure suitable for ensuring easy monitoring and inspections for structural safety? (5)
… limiting vibrations? (6)
… ensuring an easy maintenance? (7)
… controlling ongoing failure risk? (8)

TECHNICAL DETAILS:
Is the structure suitable for an easy assembly? (9)
… precast modular design? (10)
… avoiding displacements (typically outward shifting of a façade unit) which might cause the façade failure? (11)

PLUMBING SYSTEM:
Is the structure suitable for easing the distribution of the plumbing system? (12)
… ensuring a high thermal insulation of the building? (13)

Table 1. Table displaying answers.

	Composition				Structure				Technical details			Plumbing system	
	1	2	3	4	5	6	7	8	9	10	11	12	13
	H	H	L	M	M	H	M	H	M	H	M	M	H
1	L	H	M	L	H	M	M	H	M	M	H	M	M
2	H	M	H	H	L	L	M	M	L	L	L	H	M
3	M	M	L	M	H	M	H	H	H	L	H	M	H
4	H	H	H	M	M	H	H	M	M	H	M	H	H

Considering all design variants, Table 1 provides answers in terms of adherence to the abovementioned requirements: high (H), moderate (M) and low (L). At the same time, each request matches with a factor of significance (high, moderate, low) depending on the value system assigned to disciplinary contributions.

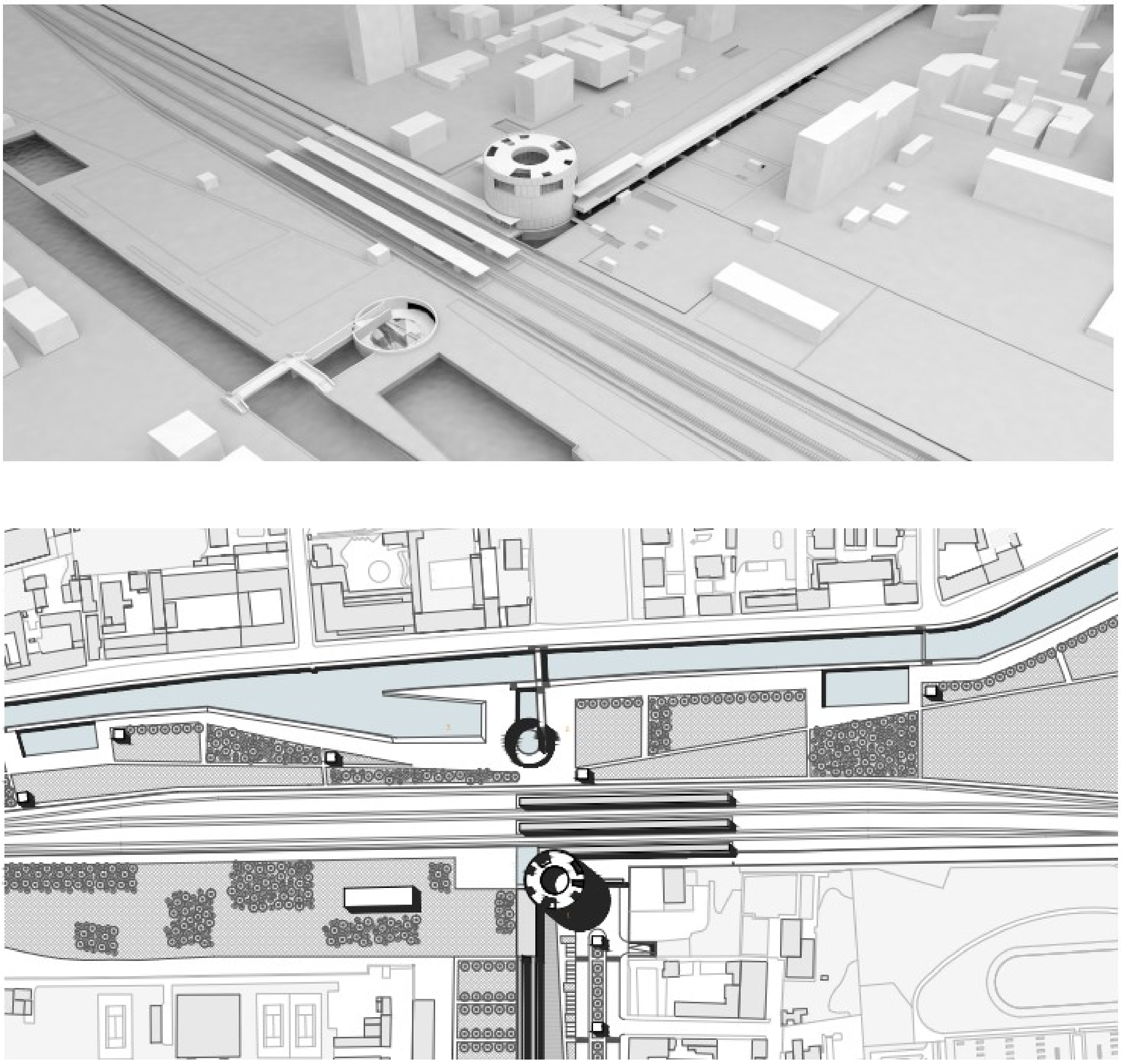

Figure 4. 3d-model (upper), planimetric and volumetric representation (lower) of the San Cristoforo's railway station project.

A score has been given to each answer: 6 points for H, 4 points for M and 2 points for B. Then the same score has been given to factors of significance. Thus each proposal's effectiveness (E) has been calculated:

$$E = \sum Pri \cdot Pdi$$

Where *Pdi* is the score given to the factor of significance of the i-quest, and *Pri* is the score given to the answer for the i-quest. Normalizing the results to the maximum value of E (i.e. 372), the above ranking has been achieved:

Table 2. Comparison between design variants.

Proposal 4	0.88
Proposal 3	0.77
Proposal 1	0.72
Proposal 2	0.62

Table 2 shows that 88% of any design request in Table 1 has been satisfied with structural proposal 4. Therefore, proposal 4 is the most suitable structural solution and it has been practically applied to design.

4 CONCLUSION

This paper briefly presents the conceptual structural design approach developed within the 2012 Architecture and Construction Design Studio (Prof. Giulio Barazzetta) at the M.Sc. Architecture of Building School, Politecnico di Milano. A project for a new railway station in Milan (Italy) was the design topic.
Basing on an "emerging design" approach, four different solutions have been defined. A multidisciplinary methodology has been developed for qualitatively evaluating each proposal. Thus the most suitable solution to satisfy design requirements in terms of composition, structure, technical details and plumbing system has been identified.
The "emerging design" approach has turned out to be more effective than traditional design approach (i.e. "top-down" o "bottom-up"). It gave a boost to architectural students in researching new and advanced solutions. Moreover it led students' decision-making process close to designer's one.

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