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Risk

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The 10th issue of the **archiDOCT** e-journal compiles papers that explore the concept of risk in architecture or that have considered risk as a key factor in their object of study. Architecture is a discipline which encompasses a vast variety of matters. These fields range from those where creativity, intuition and subjectivity play a fundamental role, to others marked by an extremely precise and technological nature. But in most of them students, docents, researchers and practitioners have to deal with risk in one way or another. As an alive and constantly evolving discipline that strives for new achievements, every new challenge in architecture frequently entails a risk of failure, non-acceptance, loss, bankruptcy, damage or even collapse. Innovation and risk are undetachable since new ideas and models may occasionally result in errors. In almost any scenario, risk is something impossible to be eradicated and then a specific strategy is required to deal with it. Each context will demand a certain attitude towards risk, which will result in a definite methodology. These tactics will depend on the perception of risk, on its holistic or fractional character, and on the magnitude of the consequences of failing. Assessing risks and even trying to quantify them constitute frequent options in fields where failure is something objective or that may endanger the whole result of a task, such as structures analysis and design, building and conditioning techniques, architectural restoration or real estate management. However, characterizing risks and learning how to live with them are usual options in fields where failure is something often subjective and affects certain aspects of the final result but not the entirety. Hence, matters such as architectural design, urban planning, landscape, graphic expression, architecture history, theory and criticism have learnt not only to coexist with risk but occasionally to flirt with it. Finally it is important to notice that the past deterministic, scientific and anthropocentric era, characterized as a time of certainties, has been followed by the current post-anthropocentric era, portrayed as a world of uncertainties and positioning risk in the centre of many exciting debates.

In exemplifying the aforementioned fields where assessing risks and trying to quantify them are a must, the paper "Reliability associated with the use of building structures analysis and design software" written by the Guest Editors of this issue, **Ivan Cabrera i Fausto** and **Ernesto Fenollosa**, along with two more colleagues from the Polytechnic University of Valencia, studies the importance of a good knowledge and expertise on the use of these applications in countries where architects have competences for analyzing and designing building structures. Due to the complexity of nowadays buildings and their structures, the purchase and use of a computer application is necessary. Practitioners want to minimize the risk implicit in the process of analysis and design of a building structure and hence they look for software which offers as much reliability as possible. But the concept of reliability of an

IT application of this kind is more complex than expected, since different aspects must be taken into account and literature about it is scarce. The paper details the different types of reliabilities inherent to the use of software for this purpose and provides some initial leads for designing tests which allow users to compare different options and might even assess reliability quantitatively.

This **archiDOCT** issue includes five papers based on doctoral research activities focusing on risk playing a major role in architecture. The concept of risk has been studied multiple, varied and interesting points of view, related to a vast range of tasks related to the daily practice of architecture such as structures, design, heritage, society and fire.

Víctor Fernández Mora, Ph.D. student at the Polytechnic University of Valencia, in his paper "Black Box Effect in the structural project: Avoiding it with BIM" deals with building structures analysis and design software as well, but focusing on its usual lack of transparency when running the calculations that doesn't allow users to verify the correction of all initial assumptions and intermediate operations. Having defined the causes and consequences of the Black Box Effect in such procedures, this paper proposes to minimize its effects by integrating the structural project in BIM since it might guarantee that users have at any moment of the process a holistic knowledge of the project.

Antonis Papamanolis, Ph.D. student at the University of Patras, devotes his article "Prototypes, models and challenges to architectural education: An examination of the role of computer assisted Fabrication in the design process" to the effects that Computer Assisted Fabrication tools might be having on architecture, from theory to construction. He states that computerized means present new possibilities and challenges, but also potential risks for contemporary architecture. What could be understood as a new design process paradigm, has advantages such as an immediate physical access to design which enables architects to examine comfortably and richly their ideas by means of full scale prototypes or models developed with different levels of detail. But Computer Assisted Fabrication tools presents also dangers such focusing too much on the details of the manufacturing process rather than reflecting on the architectural aspect of the project.

Jordi Payola Lahoz, Ph.D. student at the Polytechnic University of Catalonia – Barcelona Tech, in his paper "Design of a prototype for the doors of the organ of the Cathedral of Tarragona" narrates an actual case of this daily practice that has become a fundamental part of his doctoral research. The essay deals with the analysis and design of a new structure for the old doors of the organ of the cathedral whose current frame and paintings date back to the XVI century. The new structure has to bear two doors with a height of 7 meters and a base of 4.6 meters each one with a system of posts and diagonals that might reproduce the original one or might be inspired in other layouts employed in contemporary similar pieces across Europe that have different behavior in relation to suspension. A final design not altering too much the original system and poetry has been tested so as to add to the pre-existences as less modifications as possible but improving their performance, always alert to the risk of ruining such an important piece of the Spanish heritage.

Irem Oz, Ph.D. student at the Pennsylvania State University, in the paper "The tale of the miracle of Duisburg: A miracle or an illusion?", deals with social risk, a completely different sort of danger related to the possibility of failing when designing and placing architecture which might be understood as controversial by some people. The essay narrates the case of the mosque built in the Duisburg's Marxloh district and what surprisingly was a quite relaxed time with no protests against the building of the biggest mosque in Germany. The author investigates the reasons for succeeding and theorizes that they may be rooted in three factors: the intense participatory processes that brought many actors together, the urban location of the mosque and the visibility given to the whole process by authorities and media. However and according to the author, the final result was perhaps less positive than expected.

María Fernández-Vigil Iglesias, Ph.D. student at the University of Navarre, in her paper "Building fire risk assessment methods: A hierarchical classification", deals with fire, being one of the most famous risks in architecture. This essay considers fire a key element in architecture and argues that it may be caused by factors out of human control, but it may also be induced or catalyzed by designers, builders and users. Accepting that prevention is frequently the most effective measure to deal with fire and assuming that zero risk is not feasible, this essay makes a hierarchized review of fire risk assessment methods putting some order in the abundant but scattered literature and providing practitioners with a useful tool when looking for the best technique to be employed depending on the specific building needs.

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Reliability associated with the use of building structural analysis and design software

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Abstract

Architecture education in Spain presents a vast technical component which includes the capacity for analyzing and designing building structures. The current architectural context encompasses buildings with an increasing structural complexity which demands the necessary use of computer tools. Professionals looking for a building analysis and design software face substantial difficulties when trying to find not only a roster of commercial products available on the market, but also comprehensive studies about their characteristics, especially regarding their functionality and reliability. National codes neither standardize this type of computer tools' performance, nor supply guidelines which enable the comparison of their features and performance or, at least, which enable to validate the functioning of a certain one. Simultaneously, available international bibliography is scarce, dispersed and clueless about how to confront these tasks independently. However other neighboring scientific fields have already met the challenge of assessing the implicit risk when using certain products and tools by developing well defined methods with theoretical background, detailed principles and development criteria and quantitative assessment. Most of these methods are based in the comparison of results obtained when using a certain product or tool under controlled conditions with reference results obtained by other means. This way of working is clearly related with test beds and is easily translatable to the field of building structures analysis and design. A testbed based on a conventional building structure would enable current or future users of certain software to compare the results obtained with this application with exact values provided by other tools or methods with proven reliability which strictly apply the current regulations and codes. Thereupon practitioners would have not only an appreciation but even a quantitative assessment of the underlying risk in the use of this software application.

Keywords

Architecture; Risk; Reliability; Structural analysis; Structural Design; Building Structures; Software; Testbed.

Reliability associated with the use of building structural analysis and design software

Ivan Cabrera i Fausto, Ernesto Fenollosa, Verónica Llopis, Ana Almerich-Chuliá

1. Architecture and structural analysis and design:

1.1. Architecture's technical dimension:

In 25 BC the Roman architect and engineer Marcus Vitruvius Pollio wrote a treatise on architecture and building techniques in Rome which received the title of "De architectura". It was divided in ten books and dedicated to Augustus. In the third chapter of the first book when referring certain public buildings Vitruvius wrote:

> All these should possess solidity, utility, and beauty. Solidity arises from carrying down the foundations to a good solid bottom, and from making a proper choice of materials without parsimony. Utility arises from a judicious distribution of the parts, so that their purposes can be duly answered, and that each has its proper situation. Beauty is produced by the pleasing appearance and good taste of the whole, and by the dimensions of all the parts being duly proportioned to each other (Vitruvius 25 BC).

What would be later on known as Vitruvian triad and popularized by Claude Perrault in the summary published in 1673 should occur simultaneously, with no exception and only when perfectly balanced success could be ensured.

1.2. The structure:

The word "structure" is a cultured term, transcription and translation from the past participle of the Latin verb "*struere*", which means to build. It was initially used for architectural constructions and frequently limiting its meaning to the resistant part of the building. Nowadays, we can define the structure as the set of objects or elements placed within a building and linked among them in such a way that are able to resist and transfer to the soil the applied forces. To this end, the requirements of strength, stiffness, stability and durability should be met, as long as the aforementioned prerequisites of solidity, utility and beauty.

1.3. The structural analysis and design:

Structural analysis and design is the subject which deals with predicting and determining a structure's response when receiving a set of external stimuli usually denominated forces: static or dynamic loads, changes of temperature, building inaccuracies, etc. If the structure is being projected, its objective will be to produce an adequate structural design for the demands and goals of the project. To this end, the dimensions of the elements are to be defined and building materials are to be chosen in such a way that the structure can withstand the external forces that will be applied on it. In other words, choices have to be made in such a way that stresses and deformations do not exceed those limits that would produce failure of the structure or that would turn it unable for its function. If the structure is already built, its objective will be to check the dimensions of the existing elements by verifying the inner stresses.

In either instance, the process to be followed is composed by:

- Preliminary design:
  Alternative proposals and structural system selection

- Analysis of the selected structural system:
  Once a particular option has been selected, the design has to be developed in a sequence composed by three stages that would be repeated until a satisfactory final result is achieved:

  - Preprocessing or modelling:
    A theoretical model needs to be elaborated. It has to be sufficiently simple, but it has to be close enough to the actual structure and suitable to be analyzed by means of available analysis techniques. The model definition encompasses identifying the building bearing structure by means of determining its geometry and the sizing of the different components which constitute it; selecting the materials; interpreting the behavior of the different element joints and bearing points; and, finally, assessing the loads by means of determining their magnitude, position (figure 1), frequency, origin and grouping them in types and establishing the convenient load combinations.

  - Processing or structural analysis:
    Once the underlying assumptions have stablished, the model will be analyzed by means of an adequate method whose equations will provide us the structural response of the different components regarding internal forces and movements. In structures modelled with bars, forces in member ends and joints displacements will be obtained (figure 2). Then and based on the principles of mechanics of materials, the study of the internal forces and deformations for the different elements will be carried out. Results should be assessed and interpreted according to the adopted model in order to determine the feasibility of the selected structural system.

  - Postprocessing or final design:
    Once the internal forces and deformations for any structural component have been determined, ultimate limit states and serviceability limit states need to be checked for all of them in order to verify the validity of the initial dimensions for these elements. In the case of insufficiency, the sizing of the section should be increased. On the contrary, if the initial dimensions reveal an excess, the sizing should be reconsidered by diminishing it so as to be true to the utmost economy principle. Either way, it will be necessary to carry out the processing again, since the section properties of the different elements do affect the internal forces distribution and the displacement values for the whole structure. Not only the scarcity but also the excess when notorious might even suggest a partial or global reconsideration of the structural typology chosen. Design will be over when acceptable values for the resistant capacity and the deformability and habitability have been reached for the different structural components and for the structure as a whole.

  - Deliverables management and works supervision:
    The results obtained must be transferred to the calculations report and to the necessary blueprints to enable the structure completion. The works should be supervised in order to check that the structure final characteristics correspond to those considered during the analysis and desi   **1. Architecture and**

Reliability associated with the use of building structural analysis and design software

0,5376 KN/m²

0,8064 KN/m²

0,336 KN/m²

0,1344 KN/m²

0,5376 KN/m²

0,5376 KN/m²

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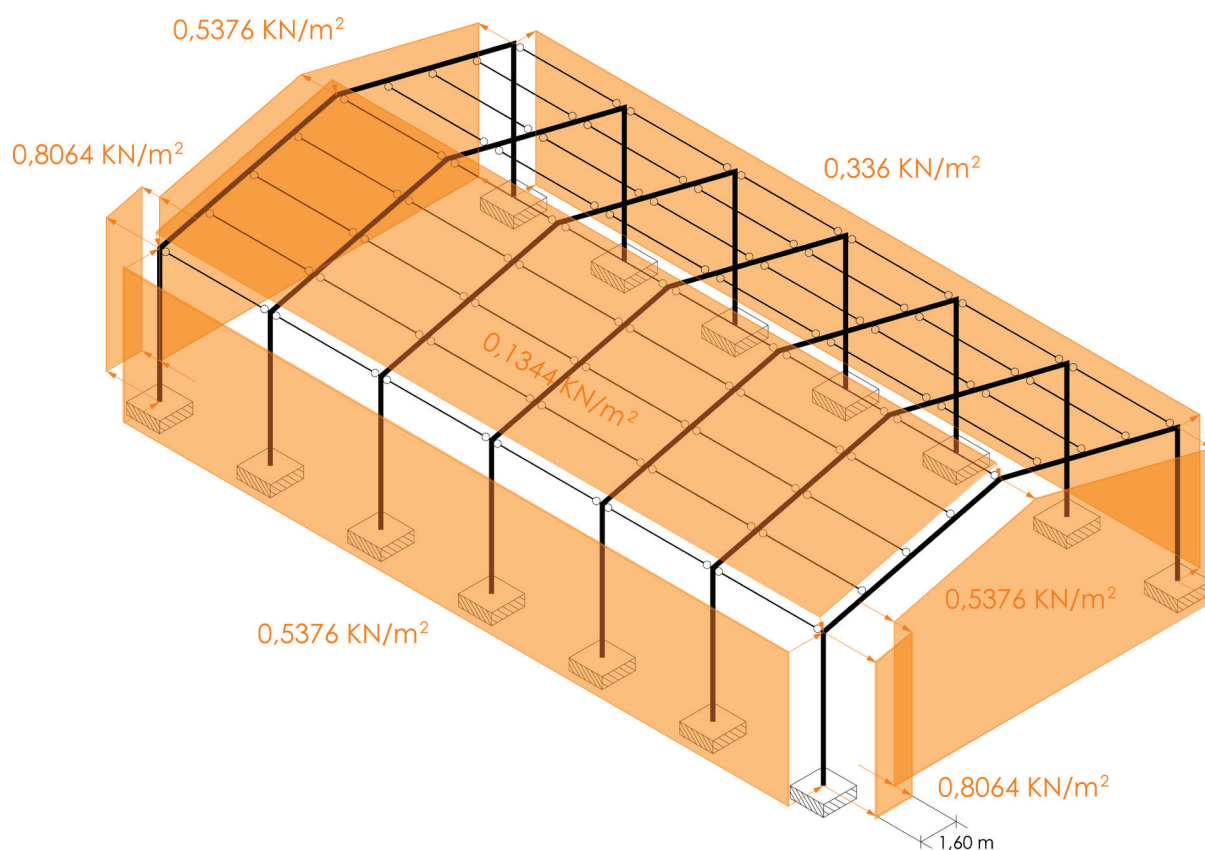
Figure 1.
Western wind loads applied on a structural model.

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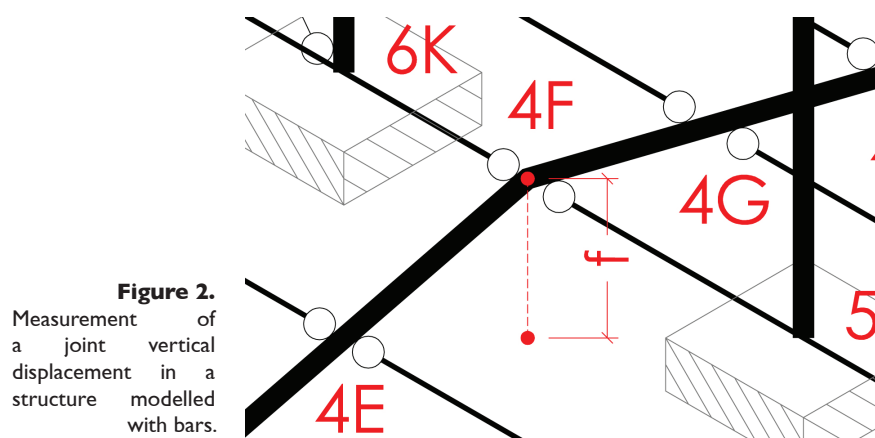
Figure 2.
Measurement of a joint vertical displacement in a structure modelled with bars.

2. Computer-assisted structural analysis and design:

2.1. The components of the evolution of structural analysis and design:

The evolution of structural analysis and design along history has been determined by the break-throughs in different subjects including:

- The development of Mathematics and Physics, especially in sciences such as Mechanics

- The introduction of new materials such as iron, reinforced concrete, prestressed concrete, timber, etc.

- The creation of new structural shapes based on the development of new building technologies

- The development of new procedures and instruments for experimentation

- The formulation of computer science techniques and the development of computers that ease the solution of the equations needed in the different analysis and design methods

2.2. Origins of the computer-assisted structural analysis and design:

In 1946 a machine called ENIAC (Electronic Numerical Integrator And Calculator) was built at the University of Pennsylvania. With more than 18.000 valves and weighing up to 30 tones, it required a room of 200 square meters (Langlais 1985). It is considered the first large scale, electronic digital computer for generic use. Anyhow, it had been preceded by many others small scale machines such as the ABC, the Colossus, the Zuse's 73, and even by other some never built examples such as the analytical machine of Babbage (Rojas & Hashagen 2000). Later on, the invention of the transistor in 1948 and of the silicon chip in 1959 kicked off an uninterrupted evolution that would stir up even the most unexpected aspect of human life. Computers have always been instruments endowed with the capacity to learn how to do any task as long as there is a way to teach them. Their development undeniably fostered the subject of structural analysis and design (Ramírez de Dampierre 1981). Since the first software for structural analysis and design was elaborated and performed in the mid-1950s, computers have been helpful for reducing the time required for calculations and have improved the design processes efficiency (Rojiani et al. 1994).

2.3. Evolution:

The development of specific software for structural analysis and design was made namely at the universities and research centers. The United States were the main hub for the development of this kind of products. We could cite plenty of examples from these times. But among them the most remarkable one is the structural analysis and design software by then called STRUDL (STRUctural Design Language) which was developed by the Massachusetts Institute of Technology for IBM and that became the reference software for many offices around the world. Starting from its original version, the Georgia Tech developed between 1975 and 1977 the GTSTRUDL whose daily use would spread over more than two decades (Rojiani et al. 1994).

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In the 1980s, the emerging expertise in the use of structural analysis and design software extended the application beyond conventional preconceived structural cases. The first studies on structural optimization appear by means of using computers as machines for analyzing, designing, reanalyzing and redesigning as many times as needed. These procedures were supposed to be automatized in such a way that computers would turn into generators of optimal structures for any building (Isreb 1984).

In the early 1990s most of the structural analysis and design software products required the data input alphanumerically with the subsequent effort and risk of committing mistakes during this process. The lack of a visual check hindered an efficient software use and demanded a significant effort in order to check the exactitude and correctness of the structural model. By then a new generation of structural analysis and design software arose with a more significant functionality since the user was able to input the data with a graphic interface making easier the structural model construction and the visualization of the analysis results (Rojiani et al. 1994). Graphical interfaces were designed so as to provide information about the structural typology, the type of structural components and the loads applied on them. It was also possible to check how the different components were assembled, which were de dimensions of each section and it was even possible to get some comments about the design allowing the user to accept or to reject recommendations suggested by the system (Biederman 1996). In the mid-1990s the cost of personal computers which could run structural analysis and design software kept the downward trend. Their progressively improving features and capacities of their central processing units opened the door to all kind of design software, even for those which implied the use of finite elements (figure 3) whose theoretical origin had been initiated several decades ago, but whose more intense development had been boosted just some years ago (Gendron 1997).

The computerization of the structural analysis and design was by then almost complete and a significant part of the vast commercial offer was also able to perform the different verifications and to design according to many specific national codes (Biederman 1996). The relentless improvements in the graphic interaction with users fostered the development of many structural analysis and design software of this typology (Rojiani et al. 1994). Any practitioner employed by then a computer in his daily duties akin to building design (Biedermann 1996). Even though the theoretical development of object-oriented programming dates back to the 1950s and 1960s at the Massachusetts Institute of Technology, it wouldn't become popular in the market until this decade. Its approach simplified even more structural analysis and design software usage since employed components resembled noticeably to their peers in the actual structure. As a result, the structural model of a building (figure 4), always being a quite complex physic-mathematic entity, could be implemented as the addition of structural elements, groups of them, joints, etc. Each part of this addition could be visualized as an independent object with different levels of abstractions (Biedermann 1996).

Structural analysis and design is subjected to a significant level of uncertainty because of the imprecise values for loads, material properties, components geometry or bearing points performance. The need for tools which could handle and compute these uncertainties gave place to the stochastic calculus software. The quick advance in computer applications in general terms during the eighties and nineties favored the development of this sort of software which was applied to a great range of problems with academic and engineering interest (Pellissetti & Sueller 2006). The effective numerical procedures behind these software considered structural uncertainties and quantified results in terms of probability. In the late 1990s, these methods were implemented in calculus environments in such a way that their management was rather easy for any practitioner (Schueller 2000).

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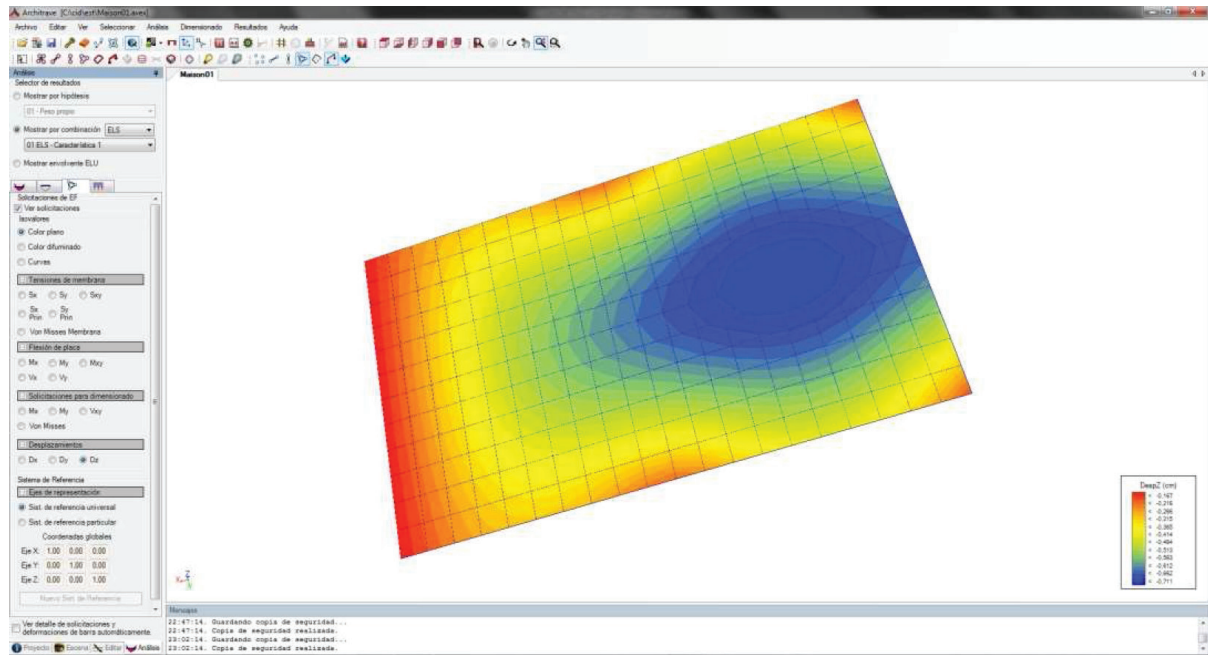
Figure 3.
Slab vertical displacements on a finite element model obtained employing the software Architrave®.
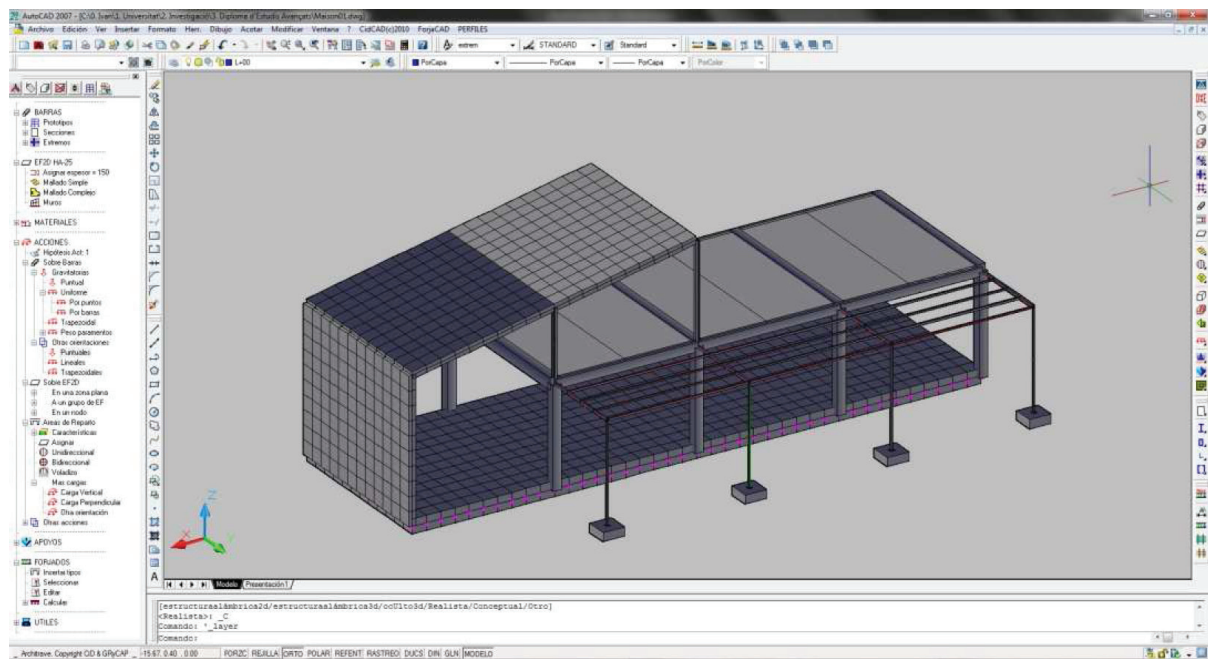
Figure 4.
Structural model of a family house during the input data process employing the software Architrave®.

Nowadays, structural analysis and design demanding high-performance is still run with software installed in individual computers, running counter to the trend of computer engineering market which has migrated most of its applications to the cloud. The emerging "Cloud computing" is a service delivery innovative model which utilizes the internet as a distribution channel (Gracia & Bayo 2013). The system structure enables users to access to a catalogue of services where only those used should be paid. Some of the products have already been designed and even incipiently commercialized identifying their modules with the traditional stages of structure preprocessing, processing, postprocessing and deliverables generator.

Finally, the wide dissemination which architectural design software based on Building Information Modelling (BIM) has nowadays, is approaching step by step the field of building structures analysis and design. If all the components within a building have been defined in the computer model, the structure as a part of the building should also be. Software capable of identifying the structural elements within these building computer models and capable of obtaining all the necessary data to define the structural model are around the corner. Having run the analysis and design stages, blueprints of the structure will be obtained normally.

2.4. Particularities and modules:

When describing any software both producers and users structure their speech in four clearly defined issues which exactly correspond to the four aforementioned stages of structural analysis and design: preprocessing or modelling, processing or analysis, postprocessing or design and checking of elements, and deliverables making (Rojiani et al. 1994).

During the preprocessing, the accuracy in the computer structural modelling performed by users has a crucial transcendence (Zhao & Zhen 2013). Making a simplified representation of the real structure involves great ability and expertise, turning this stage into the maybe the riskiest phase of the whole process as will be detailed later on.

As previously explained, during the processing the software will analyze the structure determining the internal forces, movements, stresses and deformations in the different elements that make up the structure. Its exactitude and validity perhaps is the most delicate point in the whole process. Employing a poor-quality structural analysis and design software is extremely dangerous for users, especially if we take into account that they are responsible for the software that they have chosen (Emkin 1988). Most of the software packs for building structures analysis and design are composed by closed systems which do not allow users to verify those assumptions and computes made during each stage of the process (Kao & Yeh 2014). Hence, internal forces diagrams, depictions of the deformed structure, and stresses and deformation graphics, constitute some of the few chances that practitioners have so as to verify the correctness of not only the model but also of the calculations made on it. Unfortunately, only those structural analysis and design enthusiasts assiduously and thoroughly check these diagrams and graphics, perfectly aware of their power for revealing potential mistakes. On the contrary, many others do not take the time for examining this information and just rush to get the final results of a postprocessing that might have been made on a processing full of hidden mistakes.

After the postprocessing carried out with the dynamics and limitations of the corresponding national code, the deliverables making is usually understood as the structure blueprints generation and plotting. However, plenty of structural analysis and design software can supply other informa-

tion related to the foundations and structure that might be included in the project such as the regulatory compliance report, the terms of reference, etc.

At international level and nowadays, there are numerous software packs developed for building structures analysis and design. Although preprocessing and processing modules have been developed with scientific criteria universally accepted and hence valid for any country (figure 5), postprocessing modules should adapt to the specific legislation of each state. While there are products that offer users the chance to develop this third stage depending on different national codes, the most frequent case is that comprehensive products specifically designed for their national codes are available in any country. In the specific case of Spain, the range of products is significant, but their establishment is very uneven with a reduced number of software controlling most of the market.

3. The selection of a structural analysis and design software:

3.1. The need:

The current architectural context encompasses buildings with an increasing structural complexity. New structural typologies and the arousing development of the existing ones have produced structures highly statically undetermined which have complicated gradually their analysis and design by hand. This circumstance has been especially accentuated in those structures with a significant presence of two-dimensional elements which cannot be modelled by means of bars but by means of finite elements and whose analysis without computer assisted methods is unthinkable (Gensichen & Lumpe 2008).

Therefore, nowadays practitioners must choose a software application for building structures analysis and design and incorporate it to the set of tools employed in their daily practice. Learning how to use this kind of software must happen in the schools of architecture, along with the learning of the theoretical concepts that underlie in the performance of these applications, and along with the solving of simple cases by hand that will provide students with order of magnitude and intuition about the results to be expected.

3.2. Casuistry and quandary when choosing:

Not only practitioners who look for a software application as a working tool but also university professors that need it for their teaching must face the difficulty of buying a product that fulfills their requirements. Both will find serious obstacles to find a rigorous roster of all the products available in the market and should compose an initial list with information that would come namely from three sources: commercials in specialized journals, conversations with other colleagues and compilations displayed in certain websites. It is difficult to assess the reliability and exhaustiveness of the information that can be obtained by each of these three mechanisms, but most experiences reveal that each one has certain features that absolutely characterize them.

Commercials included in architecture journals, both in the first pages or in the back cover, usually exhibit the product virtues and focus in the last update. Indeed, these commercials frequently seem much more addressed to users of previous versions than to possible new users. Only in those commercials formats with more capacity such as brochures or centerfolds, we will be able to find
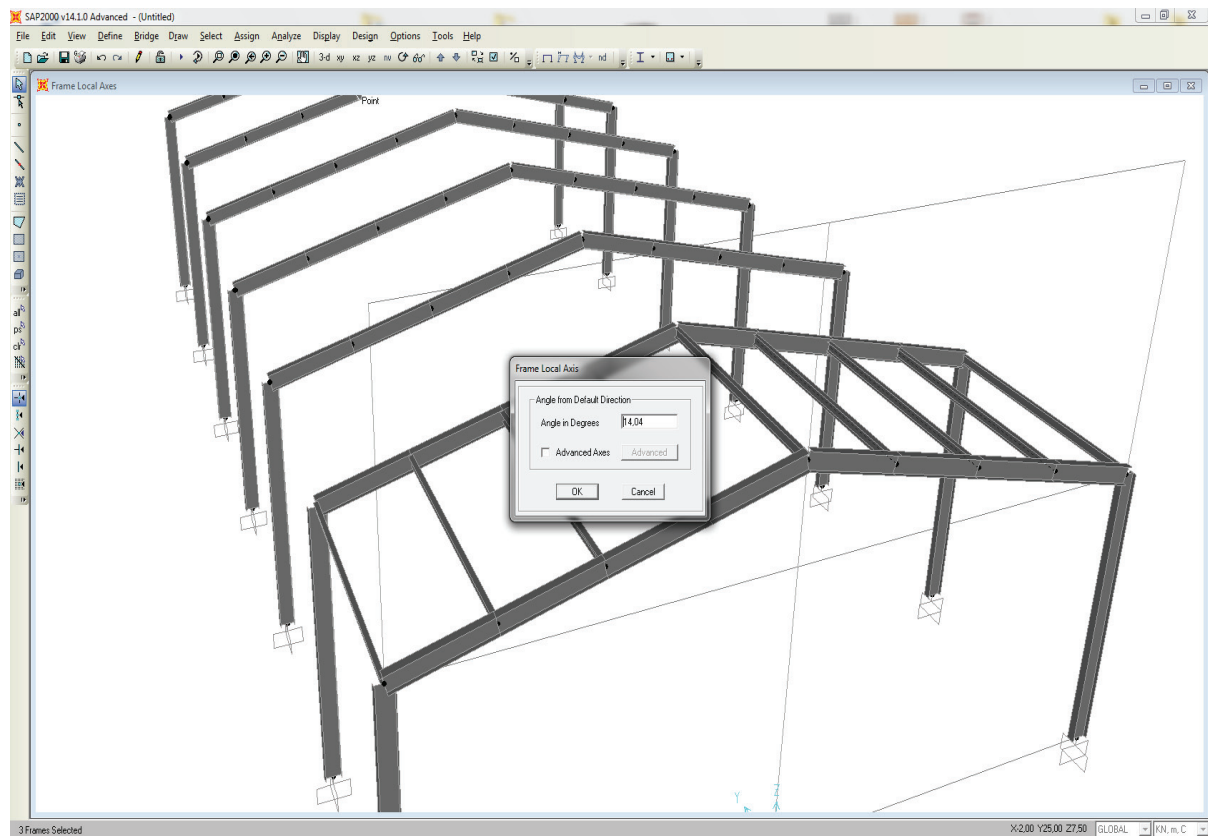
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a more detailed explanation of the application features, which, obviously, enhances its merits and mutes its scarcities. Anyhow, after a thorough analysis we will have no clue about which capacities make it better or worse than other similar products and the comparison tasks will be our responsibility.

The opinion of our colleagues might frequently be too subjective. When they made their selection it is quite possible that they didn't choose the optimal software but the one that fit their particular needs the most. Those needs in the case of a university professor might be related to the academic skills of its student and the type of lectures that must be taught. And in the case of a practitioner, those needs might be conditioned by the usual typology of commissions which receives. In any case, the final choice might have been conditioned by something completely unconnected to quality such as its price. As it happened when checking commercials, there is no reliable comments which compare different options. Anybody will justify why he or she chose one product, but mainly providing comments excessively focused in their current choice. When occasionally comments about other previously used products are provided, a narration about a bad experience that resulted in the give up of this product will show up.

Finally, rosters compiled in specialized but frequently non-official websites represent the only source where different structural analysis and design software applications are displayed on equal terms. These lists are usually limited to a more or less exhaustive enumeration of different systems and a brief description which seldom include comments comparing the features of different products. These critical analyses are namely found in opinion forums where the anonymity of users and the vehemence employed when defending certain points of view produce some skepticism.

Therefore, users eager to purchase a software application for structural analysis and design for their daily duties are rather devoid of conclusive evidence or arguments in order to choose the right option. A individual strategy will become a must taking into account the two fundamental factors when choosing a software application of any kind: functionality and reliability, which is to say the minimization of risks of any kind.

3.3. Functionality of a software application:

Any software application functionality is related to several aspects such as the facility for managing it, the capacity for limiting mistakes and the adjustment to the user's needs. Initially and apart from reliability, functionality is the feature that distinguishes one application from another and, most of the times, is the key factor when choosing one product over another (Rojiani et al. 1994). Each year industry creates a variety of applications which when already launched to the market make customers doubt about these products being adequate for their daily routines or not (Lam 2007). According to S. Redwine and W. Ridle (1985), there is a series of critical factors when the moment to use a new technology comes:

- Seriousness of the product: technology must be well developed.

- Clear acknowledgement of the need: technology must provide a response to a well-recognized and well defined need.

- Possibility to be customized: technology must be adaptable to the user's needs.

- Existence of previous positive experiences: a positive background must verify a good balance between the cost and the benefits obtained.

- Guidance: the product should include a user's guide with a large number of examples, especially in the case that new concepts come into play.

Simultaneously, there are many factors that may slow down the use of new technology and that consequently dissuade customers from buying and employing it:

- Too wide range of ways of using the product

- Difficult understanding of the new technology that involves high costs

- Large number of alternatives with different strengths and weaknesses

The final balance of all these parameters made by the customer will guide the final decision about buying or not a new software application.

3.4. Reliability of a software application:

We can understand reliability as the antonym of risk. When it comes to talk about the reliability of a structural analysis and design software application it is indispensable to clearly define three concepts which are absolutely different: reliability of the structure, reliability of the computerized analysis and design process and reliability of the software application itself.

3.4.1. Reliability of the structure:

According to Holick and Vrouwnvelder (2004), it is impossible to quantify a structure performance with precision. Thereupon, any building structure analysis and design implies uncertainty when results are displayed. Nowadays, there are techniques and methods commonly accepted in order to assess the reliability of a building structure. The most refined one is the Partial Safety Coefficients Method, based on the experience gained and in probabilistic concepts of structural reliability. Fundamental concepts on reliability are collected in the different national codes and in the International Standard ISO 2394 "General Principles on Reliability for Structures".

Reliability of the structure takes account of three fundamental factors: its strength, the service to be provides and its durability. Moreover, there are additional factors such as fire safety and other accidental situations (Holick and Vrouwnvelder 2004).

Civil structures analysis and design wouldn't be possible without taking into account the fact that there is a risk of failure during their life cycle. Assuming that circumstance, International Standard ISO 2394 defines reliability in a similar manner as many other national codes do: it is the capacity of the structure to accomplish determined requirements during its intended life cycle and under specific conditions. Therefore, in terms of quantity, reliability could be explained as the complementary concept of the probability of failure (ISO 1998).

3.4.2. Reliability of the computerized analysis and design process:

Since the 1990s, the use of IT resources to solve structural analysis and design problems is something usual among practitioners. Despite the fact that the benefits of employing a computer are undeniable, users never know for sure if results provided by the machine are reliable (Bell 1997). In this section we are not talking about the use of a stochastic or probabilistic method that aims to determine the reliability of a structure. Now we are thinking of, once any method has been chosen, how accurate are the results that software provides to practitioners at the end of the process.

Disparity between results and the values that would be obtained after a precise application of the chosen method might have been produced fundamentally by three different types of reason. The first one comes with the errors produced by a deficient employ of the structural analysis and design software. In other words, the application calculates perfectly a model which is not correct or the variables to be developed weren't properly selected. This is the type of reason that we will analyze in this section later on. The second reason comes with the mistakes produced by a deficient calculation run by the software. That is to say that the application doesn't calculate properly a model that was well defined. This casuistic will be analyzed in the next section. The third, last and most dangerous reason comes with a combination of the two previous ones which means that the model is not well adjusted to the actual structure and additionally the calculus has been faultily run. It is the most dangerous case because we would be designing a structure to withstand a set of situations that have nothing to do with those that will be faced in fact.

If the structural model doesn't represent properly the real structure, results after running the calculations might lead to a deficient structural performance and even to its partial or total collapse. All of it could be avoided if the person in charge for the modelling process and later analysis and design has the adequate theoretical and technical knowledge. In the case of having unwittingly committed any mistake or inexactitude, practitioners should be capable of running a verification of the results provided by computers. This verification should be carried out by applying the rationale so as to check that results should the practitioner's intuition and order of magnitude (Bell 1997).

A careful management of software and a critical analysis of results also provide practitioners with an estimation of the sensibility of the analysis results to the different approximations and simplifications done during the necessary discretization and idealization processes performed during the modelling (Rojiani et al. 1994). It is extremely convenient that practitioners are instructed in developing with correctness the modelling and in verifying results, since too rough rounding or approximations might lead to results that perhaps are not distorted enough to be easily detected (Melosh & Utku 1988).

3.4.3. Reliability of the software application:

As has been discussed in the previous point, even if the structural model has been carefully defined and the approximations and simplifications introduced during its preparation are reasonable enough so as not to produce a model which performs differently from the real structure, there is a last factor of risk related to the software not running the calculations well. Regardless of our trust in the software performance, once results have been obtained, practitioners should always run a series of quick calculations by hand in order to make comparisons. This verification will determine the judgment and sufficiency of results (Bell 1997). After all, computers operate following instruc-

// **Reliability associated with the use of building structural analysis and design software**
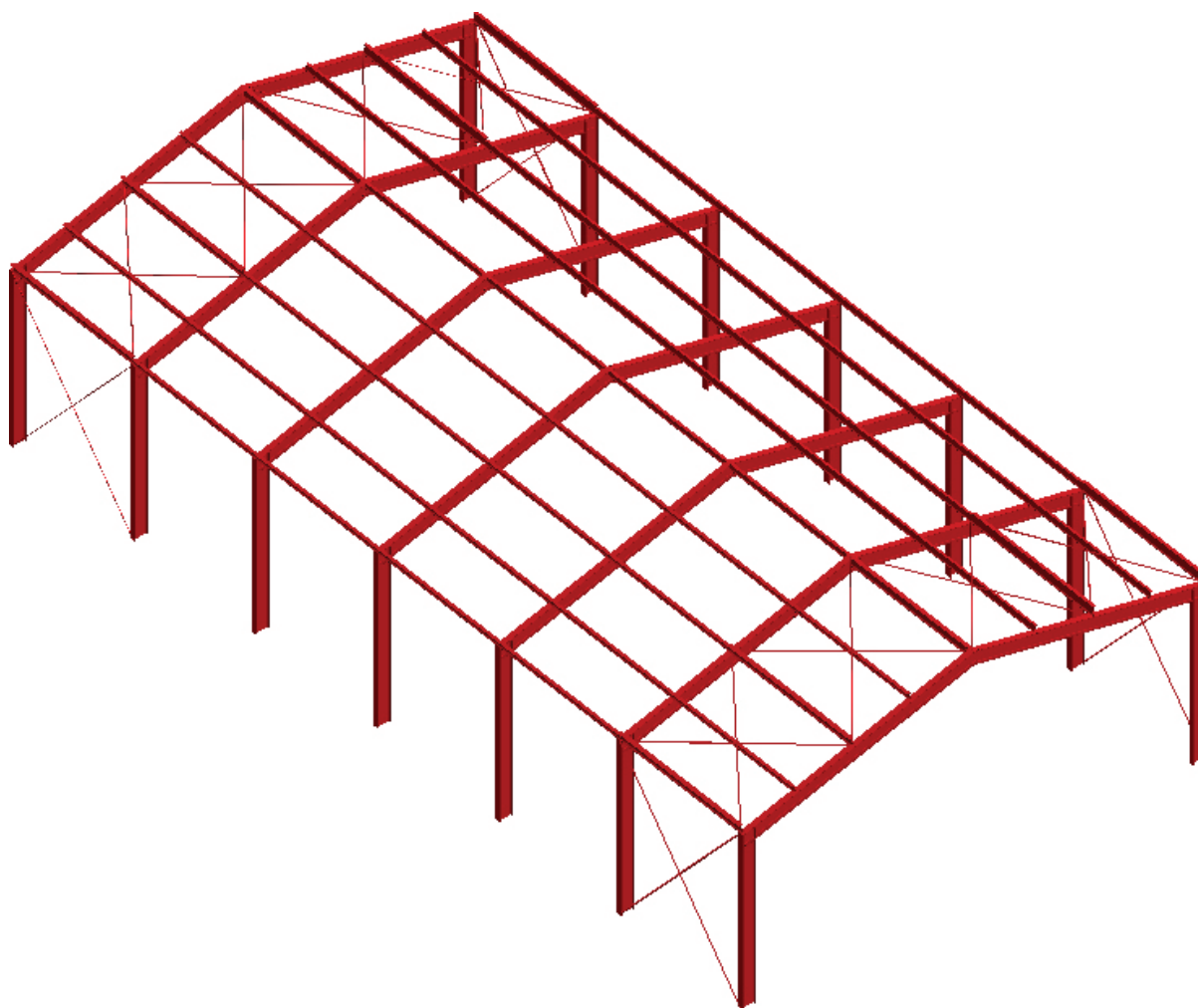
Figure 6.
Archetype of industrial plant structure employable in a testbed of reliability of structural software.

tions introduced by programmers in the structural software application and latent defects might take quite long to be detected (Ramírez de Dampierre 1981).

Against this background, it is very important to carry out a correct verification and assessment of this kind of software prior to its marketing. Likewise, the existence of national regulations and control agencies which take responsibility for the quality of software products for structural analysis and design is extremely important (Rojiani 1994). Meeting the principles compiled in these regulations and applied by the aforementioned agencies would become not only a reference to prevent the market debut of defective products, but also a tool for future users when trying to compare the reliability of already commercialized software products. Different results for the same structure provided by two different applications gave practitioners a terrible sense of unease.

We must accept that it is impossible to warrant a complete reliability for any structural analysis and design software application. Just as no scientific hypothesis can be certainly proved or discredited independently of the amount of experiments performed, we cannot warrant that any application is completely free of errors independently of the amount of practical demonstrations that we run and verify. Hence, assuming that reliability cannot be guaranteed quantitatively but qualitatively, it is interesting to develop certain tests that can foster as much as possible our trust in the accuracy of specific computer software (Melosh & Utku 1988). In this sense, a testbed based on a conventional building structure (figure 6) would enable software current or future users to compare the results obtained with this software with exact values obtained with other tools or methods with proven reliability which strictly apply the current regulations and codes.

3.5. Studying the reliability of structural analysis and design software:

3.5.1. Verification, validation and evaluation:

Verification, validation and evaluation play a fundamental role in the establishment of any software application reliability. Apart from the dynamics and methodology employed when making the product, verification and validation are the only tools that can warrant the quality of the product to the smallest detail (Wallace & Fuji 1989a). Both analyze and test the software to determine if it runs properly for its intended purposes, guaranteeing the absence of poor functioning and measuring the quality and reliability of results (Rojiani et al. 1994).

Verification is normally run by the developer of the software application and happens at any single stage of the product developing process (Rojiani et al. 1994).

Validation is the last test of a product when its development process is complete and aims to guarantee acceptable results (Wallace & Fuji 1989b). Validation implies a series of tests where the software application should solve a series of problems whose results will be compared with others whose reliability has been proven because of having been published, because of being widely known solutions, because of having been obtained safely by hand, or because of having been obtained with similar products with renowned prestige. Software can be validated when providing similar results to others available from any of the aforementioned sources (Emkin 1988).

Evaluation is focused on quality and functionality, identifying strengths and weaknesses of the software application that are not strictly technical (Rojiani et al. 1994). It is especially interesting for final

consumers since it provides information about the product ease of use (Priest 1988). Evaluation endows future users with the capacity to distinguish between one application which is friendly and another which is not and, therefore, might mislead practitioners (Vora 1986). Evaluation is developed by comparing the software pack performance in different scenarios with the performance of similar tools. It is not a simple process at all since these scenarios and categories to be compared depend quite a lot on the needs of each user. Moreover, final statements are rather subjective and almost impossible to quantify (Eskenasi 1989).

3.5.2. Responsibility on the study of structural analysis and design software reliability:

A special emphasis on guaranteeing the reliability of structural analysis and design tools is indispensable, since almost no regulation compiles a set of detailed tests to be developed (Melosh & Utku 1988). Consequently, there are few standardized case types in the field of structural analysis and design with available results to be used as benchmarks. Those people responsible for the production of this kind of software never took over seriously of the validation of their products and have traditionally trusted practitioners in determining the validity of results obtained with their software applications and their validity range. Likewise, big enterprises focused on analysis and design are understandably reluctant to devote sources for testing thoroughly structural software since testing is an intense task, that takes a lot of time and with few economic incentives. Therefore, many applications are in the market without verification or testing, or have been just roughly checked by their producers. That fact raises serious questions about their reliability (Rojiani et al. 1994).

3.5.3. Bibliography on reliability of structural analysis and design software since 1985:

Existing literature on reliability of structural analysis and design software is rather scarce. If we check the Web of Science about this topic, results are reduced an rather confusing since the term "reliability" refers to many different aspects of the analysis and design process such as the stochastic methods, the reliability of the process or the reliability of the software itself, being the last one the topic that we are really interested in now.

Therefore, a thorough review of precedents and their correct contextualization demands on one side employing as keywords for the search very generic terms, and on the other side examining carefully all the abstracts of the different papers so as to establish the final roster of documents that deal with this question.

If we check the Web of Science looking for documents which contain in its subject the terms "structural", "analysis" and "software", then refine the search filtering it only for these categories that may include papers of our field such as "Engineering Civil", "Engineering Mechanical", "Materials Science Multidisciplinary", "Computer Science Interdisciplinary Applications", "Mechanics", "Construction Building Technology", "Engineering Multidisciplinary", "Materials Science Characterization Testing", "Materials Science Composite", "Engineering Industrial" and "Architecture", and finally refine it again by filtering the results to those of areas with identic purposes such as "Engineering", "Materials Science", "Computer Science", "Mechanics", "Construction Building Technology", "Physics" and "Architecture", we will obtain 3111 results. A thorough review of all these papers focused

on selecting just those that deal with structural analysis and design software reduces this amount to 817, being the oldest document from 1984.

Figures 1 and 2 depict the number of papers published between 1985 and 2015 about structural analysis and design software. The size of each circle representing each lustrum is proportional to the amount of papers on this topic published during that period. Likewise, each circle has been divided in twelve main categories for classifying the selected papers after their study:

- Software production and its impact
- Finite element calculation
- Unconventional building typologies
- Design criteria
- Properties of materials
- Lateral loading effects
- Internal forces analysis
- Non-linear analysis
- Deformation, buckling and vibrations
- Analysis and design of joints
- Sustainability, assessment and reinforcement
- Failure and collapse

Each portion hosts a number which indicates the amount of articles published that can be classified under this category in the corresponding lustrum. By observing the sequence we can see that the production of software and its impact, which is the category that comprehends papers on this type of software reliability, was the only topic in the scarce documents published in the late 1980s. That amount grew the decade after and in the 2000s, always keeping a significant presence in percentage. Anyhow, it progressively gave prominence to papers on lateral loads such as wind, earthquakes and blast. However and surprisingly, the last five years have seen a surprising contraction of the amount of papers devoted to software production and its impact. That circumstance is rather surprising in a context where the amount of papers published every year is on the increase.

Finding bibliography which explicitly deals with the evaluation of reliability of structural analysis and design software or with comparisons between different software is an arduous task. There are few examples of papers focused on comparing results of different software applications when performing the same case, but we can list the seismic study of reinforced concrete frames developed by V. Pereira, R. Barros and M. César (2010); the seismic study of high-rise buildings with oblique column wrote by K. Hu, Y. Yang and S. Mu among other (2012); or the evaluation of the effects of a blast on light roof steel structures made by J. Geringer, C. Tuan and P. Lindsey (2013). None of them mentions any precedent neither regarding similar studies nor regarding the use of a specific methodology about how to raise comparisons.

As previously mentioned, literature about studies of reliability of structural analysis and design software is rather scarce. But still, from the 1970s until now, several science people have met the challenge of verifying the correctness and accuracy of results of several applications in different contexts. In all the cases of reliability studies and comparisons performed, the surprising absence of precedents and bibliography about how to design the process is quite remarkable. Some of them occasionally allude to previous similar studies. But no one refers to theoretical approaches, although borrowed from neighboring fields, that might guarantee the quality and impartiality of the
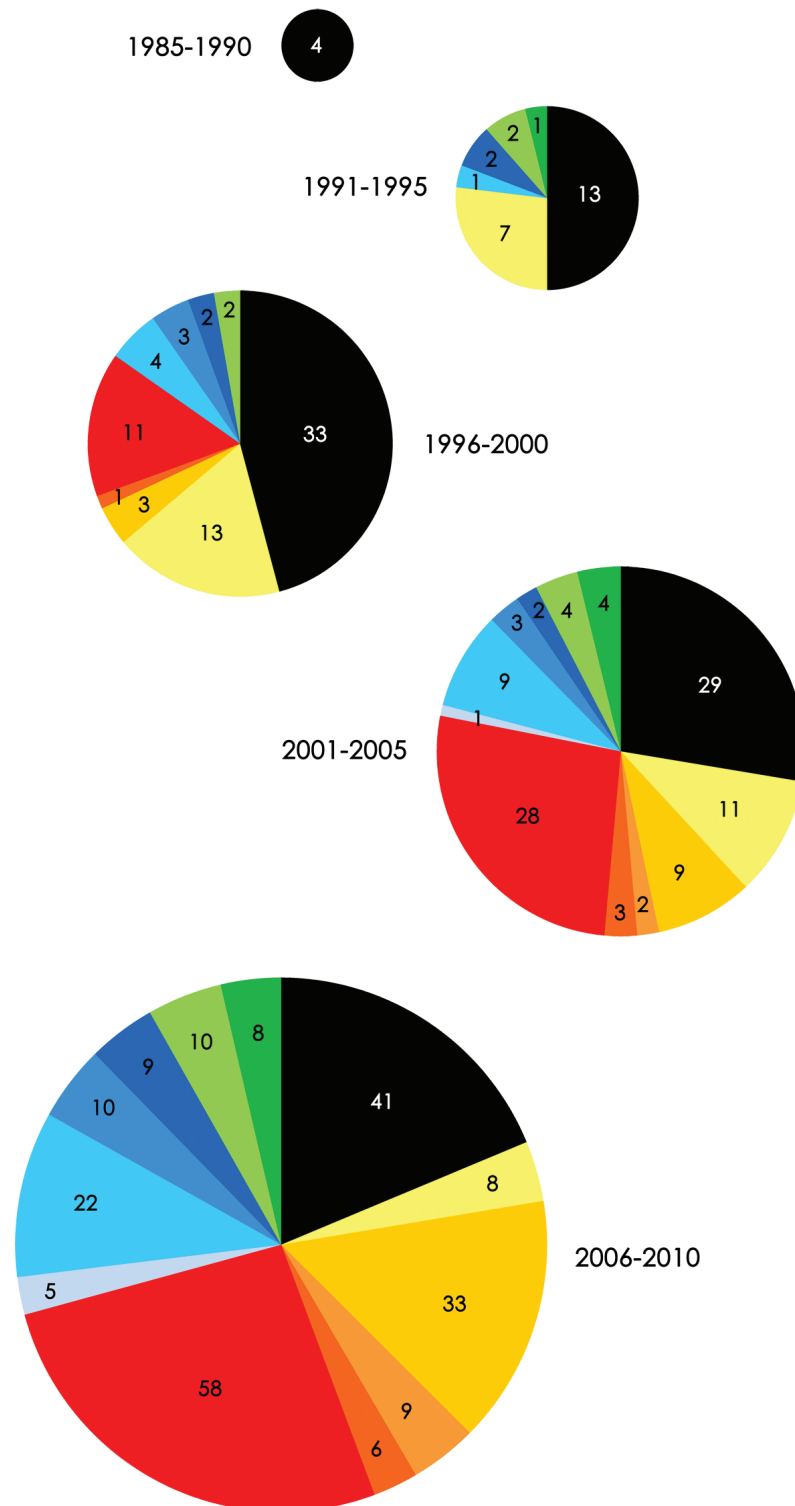
Figure 7.
Number of papers on building structures analysis and design software published between 1985 and 2010 according to the Web of Science.

Reliability associated with the use of building structural analysis and design software

2011-2015

Software production and its impact

Finite element calculation

Unconventional building typologies

Design criteria

Properties of materials

Efectos de cargas no gravitatorias

Lateral loading effects

Non-linear analysis

Deformations, buckling and vibrations

Analysis and design of joints

Sustainability, assessment and reinforcement

Failure and collapse

Figure 8.
Number of papers on building structures analysis and design software published between 2010 and 2015 according to the Web of Science

assessment process and its conclusions. At the very most, some criteria considered adequate by the authors are included but never justifying their origin apart from common sense. This lack may reside in the scarcity of this type of works, not allowing the formation of a discipline which seriously assumed the compilation of its own theoretical approaches. However, it is also true that in other neighboring fields, other authors have developed guidelines which are easily translatable to the quality evaluation of structural analysis and design software.
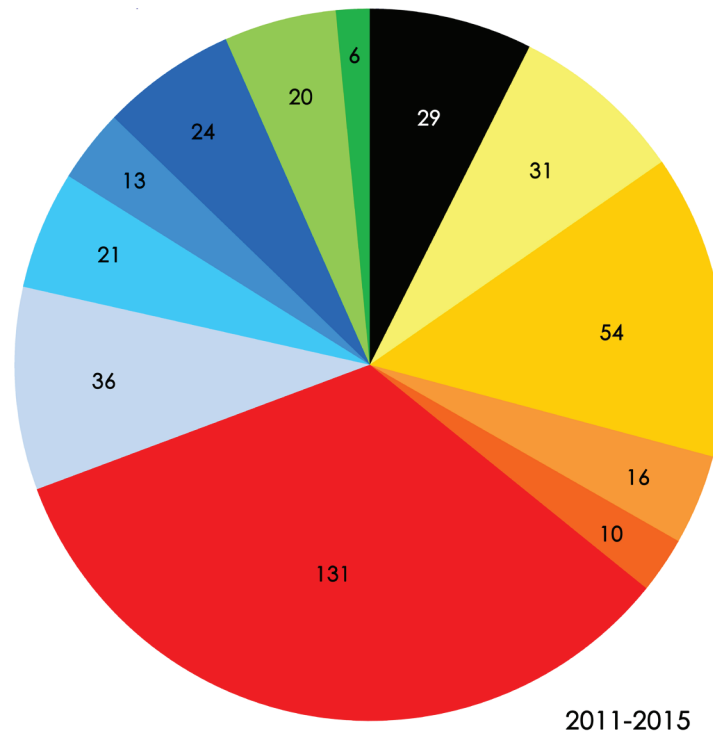
3.6. The importance of comparing results:

Most of the current codes about building structures analysis and design refer explicitly the possibility of running the structural analysis of design with IT resources. In the specific case of the Spanish "Código Técnico de la Edificación. Documento Básico sobre Seguridad Estructural" (Ministerio de la Vivienda 2009), practitioners are requested to write a report detailing their acknowledgement the software employed is adequate for the structure that has been analyzed and designed. This regulation also demands a detailed writing about how the model was input and how the results have been interpreted. Surprisingly, it never questions the software proper function and the validity of the solutions provided. However, there are other national codes which do not trust software that much in the case of dangerous buildings. So for example, the Chinese code for seismic-resistant buildings demands that the analysis of internal forces and deformations of complex structures under the effects of frequent earthquakes must be performed at least with two different mechanical models and results for both cases must be compared (National Standards of the People's Republic of China 2010).

As previously referred, nothing might look more alarming for a practitioner than the same structural model for a building structure producing different results depending on the software used for its analysis and design. Some studies reveal that dispersions can go further than 30%. That means that, at least one of the software applications employed and under comparison lacks rigor if both have been properly used (Gensichen & Lumpe 2008). Occasionally, that dispersion which immediately means suspicion is not detected in studies that compare the same case on different IT resources but during continued use of the same tool employed for solving many different cases. Dispersion of results obtained with different software applications reveals unequivocally that at least one of them was not conveniently validated. In order to reduce this uncertainty it is indispensable to assess the performance of software by means of solving cases whose results are previously known and verified, even empirically. That will allow us for certainly determining which tool has a poor functioning. When informed about the programming error that are producing this wrong results, producers will be able to remedy the internal functioning mechanisms of the tool and consequently to enlarge the scope of validity of their product (Geringer et al. 2013). Determining reliability by means of comparisons of controlled cases leads us undoubtedly to the field of test beds.

4. Test beds:

4.1. Definition:

A test bed is a system that makes possible to observe and measure the performance of a product under controlled and parametrical use conditions. This term is used in multiple fields to describe a protected experimentation environment which avoids the risk of an actual use of the tested

products which are normally in a development phase. Test beds are a rigorous, transparent and reproducible testing procedure not only for industrial products, but also for new technologies, computational elements and even scientific theories. They range from continuous improvement of new prototypes, to machines or complex systems in manufacturing industries such as the automotive or aeronautic industry (Márquez & Rojas 2011), and even to the intellectual characteristics refinement in fields such as the software products development.

Testbeds are widely used in industry and represent a significant part of the budget intended for the products design and development. Tests basically verify the correct performance of products not only in intermediate stages of their development, but also when their design is definitive. In big firms, test beds are part of the experimental general strategy, usually performed by the company itself, despite the fact that it can also be totally or partially commissioned to specialized laboratories.

Characteristics and components of a test bed depend on the format of the product to be tested. A typical one includes apparels, applications and mechanisms for networking. When a specific test demands specific characteristics or even specific models, the set composed by all these components is called test environment. However, it can also be a completely virtual environment (Lam 2007). Testbeds are equipped with an instrumentation which tests the product in operating conditions, measuring its performance by means of a series of devices. Semiautomatic test beds are those which require the participation of an operator to perform the measures. Automatic test beds are those which can control directly the measuring tools and can run the tests autonomously.

The existence and employment of test beds benefits not only developers but also costumers, since they permit not only verifying the safety of the product, but also guaranteeing that the developed products offer optimal results or, at least, those previewed by the developer (Márquez & Rojas 2011).

4.2. Design principles and criteria:

When producing a test bed it is important to have not only a good design but also precise guidelines for future users (Lindvall 2005). All the tests must be easy to perform following the recommendations about how to develop it, how to collect the information and how to write the final report (Lam 2007). That enables novel users with reduced knowledge about scientific research to take their first steps with test beds. Homogeneity when presenting the results will make easier to compare results obtained by other researchers with the consequent enrichment of the debate (Brat et al. 2004). This sort of user guide of the test bed should help potential users to become familiar with its management by means of clear guidelines or a section with frequent answered questions (Basili et al. 2001). The lack of good documentation increases the amount of necessary work which is required to run the test bed and might become one of the reasons for its failure (Tichelaar et al. 1997). Another good principle is to conceive it as an open access product, not only allowing access to it but also designing it in such a way that its employment doesn't mean a significant expense (Stone 2003). If the experimentation cost of a test bed is too high, users will be reluctant to use it and the designer's work will have little impact and will lose the chance of receiving comments and appreciations from others (Brat et al. 2004). Finally, a test bed designer should include guide lines about how to assess numerically results since one of the main objectives of users having tested different products is to know which one is the best.

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Conclusions:

Proficiency in the use of a structural analysis and design software application is important for architects in countries such as Spain, where they have professional competences in building structures. Building typologies and their inherent structures have evolved along with society, increasing their complexity and hyperstaticity. This process has been enabled by the breakthrough in different subjects such as Mathematics, Physics, Materials Science, and fundamentally in recent times by the development of computers and software applications.

Dating back to the late 1960s, computer-assisted structural analysis and design has always kept a sequence similar to the traditional manual methods and composed by: preprocessing or modelling, processing or analysis, postprocessing or design and deliverables management. Commercial software is usually marketed according to these four stages or working modules. When applications are publicized most of the emphasis is put on the variety of typologies that can be calculated and on the possibilities of the deliverables management, but few or no comments about the reliability of the results provided are made.

Professors or practitioners looking for a structural analysis and design software are not only interested on functionality but also on reliability. Information sources about this last aspect are scarce and controversial. So is scientific bibliography which in this specific field evinces a decreasing interest in this matter, making researchers step back to papers published more than twenty years ago and feel the need of exploring neighboring fields.

When talking about reliability of any software application for structural analysis and design three different aspects have to be taken into account: reliability of the structure, reliability of the computerized analysis and design process, and reliability of the software application. Being the first one controlled by the stochastic methods compiled in the national codes which set the ground for the software programming, and being the second one controllable by means of a good theoretical knowledge and a careful usage of the application, just the third one is a complete mystery difficult to unravel. Current national codes assume that building structures analysis and design software operates perfectly and no guidance to test them is officially provided.

Nevertheless, other neighboring industrial sectors and scientific disciplines have met the challenge of assessing even numerically the performance and reliability of their products, tools, applications and theories. A quick look to their methods brings us to the world of test beds whose principles and criteria might guarantee quality tools to assess the reliability of building structures analysis and design software and hence minimize the unavoidable risk implicit in designing a structure, analyzing it, building it, and finally putting it to service.

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Essays //

Black Box Effect in the structural project: avoiding it with BIM

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Abstract

The use of structural design software and their lack of transparency can provoke some uncontrolled errors in the structural design that put in danger the reliability of the structure due to the Black Box Effect. By integrating the structural project into BIM this effect can be greatly reduced. The article explores the effects of the black box in the structural software and their causes and consequences. From this point a study of how to deal with it integrating the design process in BIM is held with the will to prevent the Black Box Effect and ensure that the users have at any time a total knowledge of the project. At the end, different possibilities for the structural design project, that arise from its integration in BIM while avoiding the BBE and the advantages that the BIM environment brings to the design, are studied.

Keywords

Black Box Effect; BIM; Structural design; Architectural risk; Lean Construction.

Black Box Effect in the Structural project: avoiding it with BIM
Víctor Fernández-Mora

Introduction

Recently there has been a great change in the Engineering, Architecture and Construction Industry (AEC), due to the appearance and expansion of software based in Building Information Modelling (BIM) technology. The use of these programs has been growing since the 2000's decade and they are based in a completely new approach for the AEC. As Chuck Eastman stated, "This is an exciting time to be an architect, an engineer, or any other AEC industry professional" (Eastman et al. 2011). BIM has received a lot of attention both in the academia and in the industry, it provides technical benefits and an integrative working platform to improve the industry.

The concept BIM has experienced a significant diffusion nowadays and is used to refer to the software, the finished product or the working methodology, so it is necessary to stablish a definition. Based on Eastman's (2011) and the National BIM Standard of the United States (FAQ BIM 2016) definitions we can describe BIM as a technology related to the AEC based in the production of three-dimensional parametrical models of the project, but it is not only about the production of the models. In addition, these models must have the capacity of communicate, modify and analyse themselves. Everything in the model is updated in real time and is using parameters linked among the elements to share their properties. Thus, BIM technology has allowed us to create an n-dimensional model of a project that can be modified at any dimension at any time while keeping the parameters linked and updated.

This technology opens up a large number of possibilities in the AEC Industry as it allows a better control over the project and the exploration of new horizons to the AEC Industry. Several authors have proposed some possibilities: in (Sacks et al. 2010) and (Chong et al. 2017) we can find big matrixes analysing different proposals for the BIM future by different authors. Other researchers have started to work in a great variety of tools, to quote some interesting examples: Diao et al. (2011) present a tool that optimizes a project based on sustainability; Porwal (2012) has developed a plug-in which diminishes the trims in the reinforcement bars and Schlueter and Thesseling (2009) worked in a tool that reduces the energy consumption of the building through the life cycle. We can also find other researchers, whose work tries to implement Augmented Reality technologies or motion capture technologies into BIM (Eastman et al. 2011). Others are working in several industrialization processes coordinating the BIM with precast concrete in various ways. In conclusion, there is a lot of study being held these days around BIM, taking advantage of its potential. But if there is a main explored feature this is the process automatization in BIM.
Due to the n-dimensional nature of BIM it works like a big database with shared parameters linked between themselves. This promotes the use of different kinds of algorithms that seek to automatize several tasks. One of the most studied fields is the addition of sustainable criteria into the architectural project through the automatization at any project phase since the beginning. Diao's tool previously presented is one of these (Diao et al. 2011). We have developed a tool that optimizes a concrete beam based on economic and sustainable criteria (Fernández-Mora and Yepes 2017). There are also automatizations processes focused in other fields like the reduction of the shear amount of reinforcement bars used in slabs (Cho et al. 2014).
Every automatization developed has an overlooked risk inside it and the user can be induced to several errors by it. Automatization processes need to be previously programmed and follow different steps to arrive at a final result. The coder decides the way that it should work and has made some decisions about it, stablishing consciously or unconsciously criteria in the internal computation. The user must be aware of the internal procedure or is possible for him to commit some mistakes simply by not using the same hypothesis or criteria that the programmer. These unconscious errors are unknown by the user and are really hard to find out. What we have just described right now is

Input

BBE

Output

Figure 1.
Black Box diagram.

Introduction

In computing and engineering a Black Box is a system or a device which can provide an output from a given input, without any knowing of the internal procedures. Its implementation is completely unknown and opaque to the user (Cauer et al. 2000). This is a really wide concept and it includes almost any decision-making process -even human ones-. In this article the Black Box concept is used to describe any decision taken by the software without informing the user of it. In the AEC there is a lot of software that take this kind of decisions, but we are going to be centred around structural software only, due to big number of verifications that are held by it. There are of course, other verification processes which are affected by this and most of this research can also be applied to them.

The lack of transparency in plugins developed for BIM involves an uncertainty when using them. The more complex and difficult an automatized process gets and the more freedom that the program has to take unknown decisions, the higher the chance of errors created by the BBE. Additionally, the BBE control is more important whenever exact calculus is needed, and it becomes even harder to uncover the errors produced by it. Usually these mistakes are critical for the project's outcome. In this paper, we are going to analyse the presence of the BBE in the structural project integrated in BIM and find ways to avoid it. The first step would be to study at which point in the structural project the effect can appear and the potential errors that can cause. From there several solutions will be proposed and discussed. After that, we will argue the different ways to integrate the structural project into BIM avoiding the BBE, using the advantages that it brings.

Development

i. The computational need in the structural project

Nowadays there exists a tendency about structures that gradually increases the complexity in calculation. Historically two-dimensional structures with low hyper staticity or isostatic ones have been utilized and, this allowed them to be manually calculated. With the introduction of new structural typologies, like three-dimensional frames or two directional and waffle slabs, the structure's degree of hyperstaticity has increased. These typologies have a higher number of unknown values and need more difficult mathematical processes to be solved.

There is more than one reason to explain why the difficulty in the structural project has increased. The industry has been pushing for an augment in the demand and the requirement and to reduce the time used in developing a structural project. Moreover, the regulations have also increased the exigency and the sheer amount of verifications while new knowledge about the structural behaviour and different breaking mechanisms of the structures has been understood and studied. This obligates the structural engineer to obtain stresses and strains in a lot of points of the structure. In the end, due to these three reasons the difficulty of the structural project has grown exponentially in complexity and necessarily the professionals have to use a computer to solve it.

As tendency shows, in the near future this will not become simpler. Right now, questions away of the structural resistance have been proposed, like the sustainability or the constructability of the project and are gaining progressive importance. The classic tools have proved themselves insufficient to solve these new criteria and they are also unreachable to the hand-held calculation processes accurately. For this reason, in a near future the use of structural software will be even more man-

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datory to achieve a structural project and the software will be even harder to handle by the user.

New demands to the structural project, are an additional layer of requirements. So, to improve the current design and calculation process or to study how the BBE can be diminished we must start by analysing the working process used nowadays in different structural software. From this point, we could find a way to palliate the opacity in the software and start to add new functionalities.

As the software is essential to the structural project, we need to know how the calculation is held internally. Through history a lot of methods based on empirical experience had existed, but right now there are three that stand out from the others. These methods are the ones used by most of the actual regulations (Ministerio de Fomento 2008) and (European Commission 2010). For that reason, the structural software follows them. The first one is the permissible stresses method, based in the lineal elasticity theory and the idea of guaranteeing a stress value for each element that do not exceeds its resistance. The second one is the global coefficient method based on a condition that relates the resistance of the element with its loads. The third and final one is the limit state design method who uses this concept and a correlation similar to the previous one to compare the resistance and the loads, but this time weighted by coefficients in both, loads and material resistance (Cabrera 2016).

Regardless of the chosen method or software, the project must guarantee the reliability of the structure's final design once built. By reliability we refer to structural integrity -safety-, the tenants' security -serviceability- and of course guarantee the durability of the structure through the life cycle -durability-. According to the concept of reliability stated by the ISO 2394:2015.

ii. The design process in the structural project

In order to avoid the BBE and in addition to acquire a deep knowledge of the used software is necessary to know how and when it can appear. Next, we are going to analyse a usual structural project and find when in that process we need the software and what we are going to expect from it at any time. The analysis is based in the design process stated in Chi et al. (2014), the Fig. 2 summarizes the process.

In the structural project, there are different roles present since the beginning. Those can be carried out by the same person or not, which does not alter the design process. These roles are the architect, who is in charge of the architectural design; the structural engineer, in charge to verify and modify the structural model and also to guarantee its safety; and the constructor, who leads the building process. These three agents always interact together and constant feedback is necessary among them for the project to be completed. The structural design process starts with an architectural design at a point where structural performance can be requested to it. Due to the structural demands the project changes and adapts itself to them, at this point the most important step is to select a suitable structural typology that will respond to the requirements in an efficient way. This first attempt produces variations in the architectonical project and the subsequent introduction of new data in the structural project. This is an iterative process that goes back and forth a variable number of times until it arrives to a more definitive step of the architectural project. The first structural models are created in this phase and the dimensions of the structural elements are obtained. The architectural project is once more updated and the iterative process keeps going, this time renewing also the structural model and making each step longer and harder while closer to a solution.

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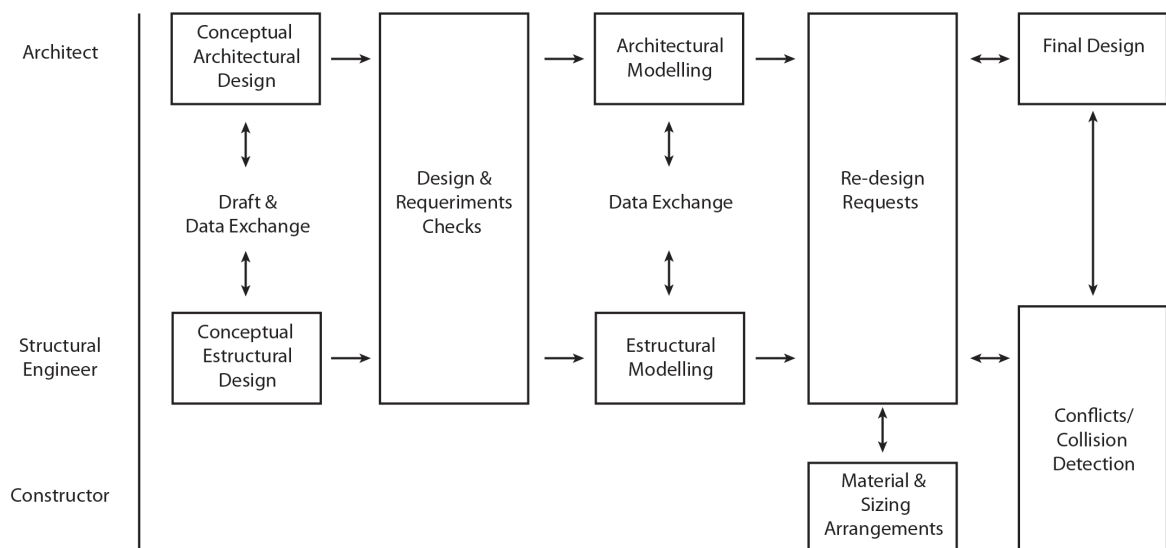
Figure 2.
Structural design process workflow diagram.

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Once the structural and the architectonical project are brought together a new step begins where the material properties are evaluated, and their availability is assured. At the construction site there can appear new issues due to difficulties in building each element. This will create modification in the structural model that will need an ulterior analysis. The design process has to add this procedure in a way according to its importance.

In recent years there a new criterion has been incorporated to the structural project, the sustainability. This criterion is mainly checked at the last steps of the structural design when there is no space for important modifications and most of the decisions have been made. So, the sustainability does not have a real chance to make a difference in the project. These verifications are time consuming and sometimes they are not worth doing when the final design is not settled because it can be wasted effort. This is mainly due to the big amount of data necessary to do this kind of verification -for example CO_2-eq.- which can only be completely acquired by the end of the project with the actual tools.

It stands out the great amount of iterations and data exchange among the different roles intervening in the design process. This implies a lot of feedback between different people that can lead to mistakes or data loss. It is very likely that the reintroduction of data in the structural model carries small mistakes, which are hard to detect, as a result of a lack of attention in the data that have been introduced or revised previously during the design.

iii. Possible errors caused by the BBE

Two things have been stated at the moment: The first one is that nowadays it is mandatory to use the computer to solve a structural project and achieve a detailed calculation that guarantees all the regulations and safety requirements. The second one, the structural design process follows a set of steps lead by different agents that cooperate between them constantly. We can also assert that there is not a single valid solution to the structural problem and this solution will not be found at the first iteration. So, as essential as it is to introduce new data several times in the structural model, each time is a chance of an error to be incorporated. There are different kind of errors that can appear:

-Data entry errors:
The most used structural software nowadays works externally to the design software. This means that when a structural model is made it has to start from a blank sheet and the data has to be inputted by the user and some deviations in the data values can arise. These values can come from the design software -project internal data- or from external sources and usually related to the structural analysis -project external data-. The repetitive modification of the data of each program can increase the error and the risk to it.

-Model errors:
The development of an incorrect structural model assuming a structural behaviour that does not correspond to the model. For example, assigning a wrong constraint to the encounter of two elements or not connecting elements that work together.

-Hypothesis errors: When developing the structural project, it is mandatory to assume some hypothesis -like the small deformations principle- most of the time determined by the calculation method used and the corresponding structural typology. The software can assume a different and erroneous behaviour or avoid some breakage mechanisms of the structure. An example of this is

the use of shell finite elements when slab finite elements are needed due to the shear stress importance.
-Construction errors:
Errors causing an unbuildable construction, by either one of these two reasons: or the design suggested by the program itself can be unbuildable -beams and cantilevers without connection, non-existent materials, etc.- or the detail solutions proposed by the software are incoherent with the design -reinforcement bars that do not fit, non-weldable joints, etc.

Although experience is considered a great criterion to avoid the previously mentioned errors -because it provides to the user with an extra control tool- it will not avoid them always. Nevertheless, a deeper knowledge of the used software, will help to interpret the results and the data requested by the software in a better way and also avoiding mistakes. Therefore, even if they are completely considered, either of these two possibilities guarantee the completely avoidance of the errors and they are less advantageous the opaquer the program gets.

The BBE is not always responsible for the errors previously listed. Neither can we say that they are failures in the software, which probably has responded perfectly to the given instructions. Probably, the user is the culpable of these mistakes, but a better communication between the structural engineer and the software entails a higher ease to detect the errors and to reduce the risk of making them.

Results

i. Solutions to the BBE

The main cause of the BBE is a lack of transparency in the structural design software. This can provoke some of the errors previously stated. To avoid the effect and to reduce the risks related to it there are two possible solutions, which both modify the actual operational sequence of the software.

The first solution is based in increasing the software's transparency. So, to say, the programs need to show to the user the different steps kept to do the operations and every hypothesis is exposed to the user. To create a software with this in mind would erase the BBE, but it would also delete almost all the advantages of using structural software, because by continuously showing all the data to the user the automatization of the process becomes diminished. Neither would it be suitable for other reason, the computer process develops itself at high speed and a person is unable to keep up. Even if the process stops at each step to show the results to the user, the enormous amount of data will overwhelm him. At the end, the data would be ignored assuming that it is right. So, even if the steps are shown, that does not mean that

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the user gives them proper attention either makes them easier to be checked.

Nowadays the program CYPE[1] uses a similar method to the proposed one, it allows the user to know step by step where the program is in the process and later -when all the calculations have been done- the user can access the results for each structural element. This leads to the stated beforehand, during the calculation step the notifications are shown at such speed that are almost impossible to be followed by the user and later is hard to revise the huge amount of data which normally overwhelms the user who centres the efforts in the main elements and can oversee the mistakes.

The second solution consists in showing an estimation of the result to the user. In this way if the final solution differs from the expected one, the user is conscious that an error has been made. The problem of this approach falls on the fact that the main reason to use a structural software is the ignorance of the result, so to be in the need of knowing the result beforehand to verify it, is quite contradictory.

This can seem like a dead end, but in fact, it points to the right way. There has been a key factor left behind, to have an appraisal of the result and knowing the exact result are two completely different things. To avoid the BBE is enough to have an accurate estimation, a wide range of values where the final solution would probably lay. The smaller that this range of solutions gets, the better of the prediction and higher the control over the project. The method used to get to the rough number shall determine a pre-dimensioning and must reflect in the most accurate possible way the expected structural behaviour, because it needs to have into consideration the most critical breakage mechanisms of the structure. It is possible to have a range of solutions from the beginning if the structural engineer is quite experienced, but as we discussed before, this is not a factor that we can bear in mind. To control the BBE a rough number has to be kept in mind at any phase of the project.

ii. Erasing the BBE through BIM

Working with possibilities that both reduce the influence of the BBE and coordinate the previously stated solutions is something natural for the BIM methodology by using its advantages and working methods. Remember that when working in BIM the user is virtually building the project, not just drawing it in a three-dimensional space. The project is an n-dimensional build which has great control over all the parameters in it. This is one of the great advantages of BIM; the user is able to work with parameters of different kinds since the beginning and to take them into account. With this it is easy to diminish the BBE and to keep the structural design process.

1. CYPE is a compendium of different technical software developed by CYPE Ingenieros which is able to assist the AEC professional during the different verifications in the project. It can verify structures and installations, write reports, make budgets, etc.

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From the previous analysis, we can conclude that doing just one attempt at the structural project may accent the BBE, because there is less control over the real structural behaviour. So, the best strategy is to make iterations that slowly approach to the final solution that coordinates the structural and architectonical design. The studied design process already uses this method and keeps evolving the project whenever there is a modification, but due to the restrictions in the models and the amount of time required to re-elaborate them, normally the number of iterations is kept low. So, to implement a way against the BBE the existent working process among the different roles can be of use.

The integration of the design process into BIM allows a potentially infinite number of iterations and modifications over the structural model with almost no effort. It also implies that the architectural model can be modified according to the structural model requirements, in fact they become the same model. Moreover, at any time, modifications and verifications can be done. The data is inside the model and can be easily accessed and verified. This data keeps growing in number as the model progresses allowing the user to have more control over it. So, to say, since the beginning of the architectural model there are some rough numbers that can be done working fully into BIM using the data inside the model. This process can keep going while the data grows and the tests can be more accurate the more the model advances in its design and everything is available to the user. And there is no drawback either if the model is updated by several people. For example, an architect and a structural engineer working at different places or times, because the BIM model can be uploaded to a cloud server and developed from there. Fully integrating the structural design process into BIM does not greatly diminish the BBE, it almost erases it completely. If used in the right way it can avoid any of the mistakes that lead to the effect. On the one hand, there are no data entry risks because the data is always stored in the BIM database and there is no feedback between different software. On the other hand, the ease to repeat the structural computation complicates the existence of model errors or hypothesis errors, because by simultaneously observing both the architectural and the structural model is easy to coordinate the mechanical mechanisms between them. And also for this reason, the construction errors are easier to prevent.

The space for improvement of the structural design project by the use of BIM does not end here. Thanks to BIM being a n-dimensional model, new dimensions can be added to it and from there the structural project can be improved. I can easily incorporate new criteria like sustainability into the project, through a dimension that allows controlling it -like CO_2-eq.-, or using several dimensions together to implement optimization algorithms in the structural elements to obtain the best possible solution for each element based on their performance in those dimensions. The potential for BIM is limitless right now and it can avoid the BBE with ease while incorporating new tools which right now are still undeveloped.

Conclusion

In this essay, risks derived from the BBE in the structural building project have been revised, which is to say, the risks of committing a mistake due to the lack of transparency of the structural software. In addition, the causes of this effect have been exposed and the errors motivated by it have been classified. Finally, two ways of diminishing the BBE have been studied and the advantages and method of integrating them and the structural design process into BIM have been discussed.
Next, we are going to quote the most important reached conclusions:

-       The black box effect is a real risk that can induce important errors in the structural project which can compromise the reliability of the structure.

-       The most important thing to have in mind when using a structural design software is a critical view over the results obtained and the ability to check them.

-       It is necessary a deep knowledge of the software chosen for the structural project to be able to understand the results with accuracy.

-       A great way to reduce the BBE is achieved integrating the structural project into a BIM environment.

-       The BIM environment offers a huge number of new possibilities to explore in the structural project and they allow the project to focus the study from new points of view and to take into account new factors that previously were almost impossible to handle.

The use of BIM is not only attached to advantages, like every method it has its drawbacks and deficiencies. It is a new paradigm with great potential and unknown limits, but with a completely different focus that the one used until now. To project using a Building Model implies that the team knows and assumes the corresponding methodology. In the contrary, taking BIM can be a total failure and cause some unwanted effects even worse that the ones that are prevented or the achieved advantages.

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Prototypes, models and challenges to architectural education:An examination of the role of computer assisted fabrication in the design process

Prototypes, models and challenges to architectural education: An examination of the role of computer assisted fabrication in the design process

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Abstract

It is a well-documented fact that the effects of the information age are felt across the whole spectrum of the architectural field, from theory to construction. Among the trends that have emerged one can cite the increased interest in digital fabrication methods, utilized in the creation of architectural models using numerically controlled tools. These approaches are commonly - albeit inaccurately- associated with the term prototype. Nevertheless, the implications of this phenomenon are numerous, ranging from practical considerations regarding the expedience of the new methodologies to theoretical ones, such as to how does "prototyping" affect the architectural model and by extension the design process in general. Computer Assisted Fabrication can be viewed as part of the general trend towards digital media in design and also presents new challenges and potential risks for contemporary architecture. This paper, which is part of a Doctoral research on the impact of digital media on architectural education, will attempt to explore some salient issues of computer assisted fabrication in architectural design, focusing on the educational aspect. Certain implication of these issues as well as proposed frameworks for contextualizing them will also be briefly discussed.

Keywords

Prototyping; Digital Fabrication; Model Representation; Design Process; Architectural Education.

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Introduction

The Oxford English Dictionary defines "prototype" as:

- The first or preliminary version of a device or vehicle from which other forms are developed.
- The first, original, or typical form of something; an archetype.

Alternatively, in the Merriam Webster Dictionary "prototype" is defined as:

- An original model on which something is patterned (ARCHETYPE)
- An individual that exhibits the essential features of a latter type
- A standard or typical example
- A first full scale and usually functional form of a new type of design of construction (such as an airplane)

It is of certain interest to examine the definition and application of the term "prototyping" in contemporary architectural discourse and the effects it has on the architectural field. Both in the sense of a new technology utilized in the design process as well as in the context of conceptual model of architectural praxis. It is argued that this examination can lead to the identification of certain challenges facing contemporary architecture as well the risks inherent in these challenges, Furthermore, it is contended that the phenomenon of "prototyping" in architecture and the questions it raises can be approached in the context of a broader theoretical framework. Finally, the utility of such a framework in the articulation of architectural culture as well as the questions raised by "computer assisted fabrication", especially in a pedagogical setting will be briefly discussed.

In order to highlight certain salient issues in this direction, this article will attempt to:

- Explore how the concept of "prototype" affects architectural thinking and praxis
- What do we mean by "prototyping" in an architectural context?
- Do "prototypes" influence the design process?
- What are the challenges and risks posed by the adoption of the new technologies?
- Interpret the role of "prototyping" in architectural methodologies in a theoretical context

Defining Prototypes

William Mitchell wrote that the modernist motto "form follows function" lacks meaning if we cannot specify what form, function or even follows means [Mitchell 1990]. Bearing this in mind, it is of interest to examine what we mean when we utilize the term "prototype" in an architectural context. Such an inquiry is of additional use in order to avoid the pitfall, all too common in architectural discourse, of utilizing terms and concepts that originated in other fields, without properly translating and internalizing them. This process of interpretation is conceived along the lines of a "transcoding" process as proposed by Frederic Jameson [Jameson 1981].

When one speaks of prototypes, one of the first images that come to mind is an experimental construct, usually a machine that, as the definition cited above states "exhibits the essential features of a latter type". For example we could imagine a prototype airplane that precedes the full scale mass production based on this test model.

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In the case of architecture, one would be hard pressed to state that prototyping plays a similar role to the one described above. With the exception of parts that are mass produced to construct a whole architectural element (e.g. panels for a facade) there are few occasion on which design has use of mass production.

Nevertheless, the terms "prototype" and "prototyping" are common in architectural discourse, spawning multiple approaches that mostly structure design methodologies around computer assisted fabrication in some form or another. One could argue that in the vast majority of the cases, the process described is not actually "prototyping" according to the definitions described above, but rather a form of model making, or representation, in the sense of a method, or design world [Mitchell 1990] that aids in the articulation of the design.

For the purposes of this paper, the term "computer assisted fabrication" will be utilized to refer to the approaches described above. This is in order to avoid confusion regarding the difference between "prototype" and "model". Although admittedly as has been already mentioned, there is little true prototyping involved in architecture at least in the industrial sense, it is valid to point out that there is widespread use of modeling as a means to test architectural design proposals. Computer assisted fabrication effects in this regard are twofold.

On the one hand it affects the modeling process described above, on the other hand it could be contended that digital tools could allow for the introduction of "prototyping" in the design process along the lines by which the term is used in other fields.

It is argued that regardless of the semantics of the term, it is a fact that the introduction of "computer assisted fabrication" in contemporary architectural discourse is viewed as a new design process paradigm [Kolarevic 2001].

Prototypes and Models

Computer Assisted Fabrication arguably falls under the domain of model making, i.e. the physical scale models architects produce during the course of a design project. Although it escapes the scope of the present paper, it is interesting to note the differences between "model" and prototype" and the risks involved with their misuse in current architectural discourse.

In any case, as a model making method, Computer Assisted Fabrication can be categorized in three distinct groups. Conceptual models, used to articulate a design idea, exploratory models, utilized in the testing and judge design concepts and presentation models, and finally presentation models which are part of the final demonstration of the design product to others [Kvan et al 2001]. The different roles these models are called upon to fulfill result in different characteristics in each group. As a result, conceptual models may be more abstract and their making process more ad hoc. Similarly, exploratory models may incorporate material considerations and precise dimension in order to evaluate a specific aspect of the design, such as morphological, structural or functional considerations. Finally, presentation models usually contain a high level of detail and similitude to the final project in order to be understood by the broader public [Kvan & Thilakaratne 2003].

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The role and importance of model making is well documented in architectural theory [Tsou et al 2001]. The physical model allows an unmediated inspection of the design, and is especially useful to examine spatial sequences and geometric form [Sass 2004]. These aspects of the design are usually difficult to discern in architectural images such as sketches, layouts, 3d models etc [Stavric et al 2007]. Therefore the physical model retains its importance in the design process despite the proliferation of digital media that have subsumed almost the totality of drawing representations.

Contemporary approaches to modeling as described above focus on the utilization of digital tools in the fabrication process [Valdés et al 2013]. This allows for the representation in physical form of the complex geometries that usually accompany the use of computational media in architectural design [Klinger 2001]. Beyond this ability to realize the new forms of digital design, these tools also allow for greater precision and speed in the creation of models [Kenzari 2005]. Therefore it might be argued that modeling using digital fabrication tools has the effect of returning to physicality the architectural forms of the digital age that display an alarming tendency to drift into disembodied forms in cyberspace [Lynn 1999] and create an emancipated reality in place of the holistic representation required to conceptualize the totality of the architectural project [Vesely 2005].

At this point it must also be mentioned that Computer Assisted Fabrication is not limited to scale models of the kind described above. The existence of an uninterrupted flow between design and construction through the use of CAD-CAM systems allows architects to have immediate access to the building site itself, creating the tantalizing vision of a designer – fabricator that is present in all stages of design from conception to construction [Clarke 2004]. It is worth noting that this could be a paradigm shift comparable to the evolution of architects from master builders to creators of representations, that all drawings and models ultimately are [Vesely 2005].

The Technology and Risks of Computer Assisted Fabrication

As has already been stated, contemporary modeling methods are closely connected to the introduction of digital tools in architectural design. Beyond the existence of computational design media capable of creating and manipulating complex forms, Computer Assisted Fabrication requires a series of numerically controlled machines, such as CNC routers, laser cutters, 3D printers and the like [Pupo et al 2009].

It has been often noted that the whole concept of Computer Assisted Fabrication is approached from a technical standpoint rather than as a design issue [Streich 1991]. In other words, many approaches focus on the details of the manufacturing process rather than examining the architectural aspect of the project. Therefore there is a risk of not addressing purely architectural consideration such as aesthetic or design intent and limiting the methodology to a how to" manual of prototyping.

It is also interesting to note that older approaches focus more on the technical descriptions of the digital tools used in prototyping. As a result one can read a detailed description of e.g. stereo lithography [Streich 1991], whereas more contemporary approaches take 3D printing for granted and focus on the actual manufacturing process [Marcus et al 2014]. One can argue that this evolution indicates a shift from the "how to do" to the "what to do" [Cabrinha 2006] in prototyping and at the same time that this signifies a certain lack of authorship. In other words, by no longer finding and describing the processes that fit our design intent but rather adapting our projects to fit the available tools. One can conceivably argue that this presents the risk of tethering design intent to technological elements that is doubtful can act as the generators of architectural meaning [Vesely 2005].

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In any case, as has been mentioned above, information technologies allow the creation of a continuum in the design process from drawing to realization, although it remains an open question if the architect can retain a holistic supervision of all different aspects or there if there is a need for specialization and one cannot expect a designer to be proficient in all stages of this CAD – CAM process. Therefore, one can pose the question if Computer Assisted Fabrication favors a holistic approach to design or risks further fragmenting the design discipline into autonomous specialist fields.

It is obvious that these challenges and potential risks go beyond a narrow technical approach. Furthermore, there are obvious risks in ignoring this aspect of Computer Assisted Fabrication. It can be theorized that it is the role of architectural culture, to address these issues, in the light of the parallel discussion regarding the use of digital design media. Furthermore, I believe that contemporary architectural education frameworks must address the questions raised by the new design paradigm.

Designing as Computer Assisted Fabrication

Beyond the aspects of Computer Assisted Fabrication briefly analyzed above, an important issue is how these methodologies affect the design process itself. In other words, do they affect the resulting architectural product in the same way that digital design media does [Kolarevic 2000]? Or do digital fabrication methods offer little more than a practical expedience to the slower and less precise analog methods of model creation?

First of all we must mention that these tools remain comparatively expensive and therefore are not readily available [Lara et al 2009] in the same way that design software packages are. To put it simply, architects are much more likely to have access to a computer than to a CNC router and as a result the computer – and therefore the digital design software is more likely to affect the design than the digital fabrication tools. This hypothesis is supported by studies examining the behavior of students with regards to fabrication labs, where the most extensive use is observed during the final presentations [Rügemer 2008] which means that the project has been all but finalized, and there is no opportunity for the digital fabrication of the "prototype" to offer any feedback or insights to the design. One can argue that dedicated workshops centering on prototyping might offer an alternative educational method [Hemsath et al 2009], but this runs into the problem of being separate from the design studio that is the linchpin of architectural education strategies [Kvan 2003]. What is more the limited time of such workshops doesn't allow for a thorough articulation of a design proposal, a fact exacerbated from the need to also introduce prototyping tools and their use to the students.

In any case, it must be admitted that even in today's limited fashion, Computer Assisted Fabrication tools are affecting design [Diniz 2015], either through the realization of complex forms of digital software, either by creating a loop between drawing and modeling [Arpak et al 2009]. What is needed is an introduction of the fabrication processes in the design studio as well as a larger number of machines to allow better access to students. And while the hardware aspect is harder to tackle given the realities of academic budgets, it can be argued that a better integration of Computer Assisted Fabrication methodologies during the course of design studios can benefit the educational process significantly by increasing the exposure of students to such methods in the context of their own design projects, offering feedback that informs the designs' evolution instead of merely actualizing the final product and lastly maximize the efficiency of the limited resources available to architectural schools [Pupo et al 2008].

Prototypes, models and challenges to architectural education:An examination of the role of computer assisted fabrication in the design process

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Representation and Computer Assisted Fabrication

Thus far we have described the relation of Computer Assisted Fabrication to architectural models, mentioned the technical focus of design modeling methods and briefly analyzed the impact of fabrication on design process especially in an educational context. In order to outline a possible holistic conceptual model regarding the use of Computer Assisted Fabrication in design, it will be attempted to examine the implications of the previous observations in a non-deterministic manner in contrast to a technological approach common in relevant discourse. To that end, concepts drawn from the field of hermeneutics will be utilized.

It has been argued that the design process is in essence a hermeneutic process [Schon 1987], in other words, that the architect enters into a dialogue with the project. This process cannot be examined solely through the lens of deterministic logic, since its workings include elements and mechanisms of a hermeneutic nature [Snodgrass and Coyne 1997]. It is not possible in the context of this paper to further analyze this position, suffice to say that methods and processes that focus exclusively on the quantifiable part of the design process, such as computational design media or arguably digital fabrication techniques ignore crucial elements of the architectural project [Gu et al 2010] [Davis et al 2011].

But how does this reflect on the use of Computer Assisted Fabrication in architectural design?

On the one hand, as has already been mentioned, the focus on such approaches is on the technical aspect, i.e. the "what" and the "how" of design [Sommer & Palz 2009]. This leaves the important question of why, which is of crucial importance to a design project as well as an educational process, [Kastoriadis 1991]. Current Computer Assisted Fabrication approaches share this issue with the broader field of digital design theory and praxis, i.e. the lack of a critical view of the various design methodologies. It is useful to cite Mies van der Rohe's statement, that the how we build is not as important as the spiritual issue of why we build [Neumeyer 1991]. In light of this, it can be argued that there are benefits to approaching fabrication as a design world [Mitchell 1990] in which they can enter into a dialogue with the design project and within which prototypes are considered arguments in this dialectical procedure rather than finalized products. This view is corroborated by studies indicating the importance of feedback from Computer Assisted Fabrication that informs the design process, as has already been mentioned [Yazici & Gerber 2016].

On the other hand, the fact that Computer Assisted Fabrication methodologies succeed in rendering in physical form the complex geometries and multiple alternatives associated with computational design can be seen as a positive factor inasmuch as it aids in the tethering of architectural space in physical reality [Kvan et al 2001]. All too often digital media lures designers into the digital exploration of abstract geometric spaces that retain little or no link to the physical reality into which architecture must conceivably exist. The ability to rapidly translate these complex forms into tangible objects aids in the better appreciation of various aspects that the -ultimately two dimensional- nature of an image can obscure [Stavric et al 2007]. Furthermore the physical aspect afforded by Computer Assisted Fabrication methodologies allows the appreciation of architectural objects with other senses other than vision, senses that are equally important in the way we perceive space [Pallasmaa 1996]. It is interesting to speculate if current developments in virtual or augmented reality will affect the need for tangible models in design process, but that discussion is beyond the scope of the current article [Coomans & Oxman 1996].

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Conclusion

An attempt has been made to examine certain aspects of the architectural discourse in the field of Computer Assisted Fabrication. Although the nuances and particularities of the numerous methodologies cannot be adequate addressed within the limits of such an approach an effort has been made to identify a number of salient issues and analyze them in the context of the design process per se as well as part of contemporary architectural culture and pedagogy.

In order to further analyze these themes, it is suggested that they must be viewed under the lens of a broader conceptual framework. This framework can aid in conceptualizing Computer Assisted Fabrication as means of representation according to Gadamerian hermeneutics, i.e. of the object of representation being present in the only way available to it, not as an inferior simulacrum [Vesely 2005].

In this sense, Computer Assisted Fabrication is approached as part of a broader dialogue in which the "how" and the "what" do not risk eclipsing the "why" of architectural design.

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Design of a prototype for the doors of the organ of the Cathedral of Tarragona

Design of a prototype for the doors of the organ of the Cathedral of Tarragona

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Abstract

A real project motivated this article about analyzing, checking and designing a prototype for the stretcher of the doors of the Organ of the Cathedral of Tarragona. But its shorter length gives it more freedom to get theoretical conclusions, having no information and details from a longer analysis and new details founded during future site works. The main topic developed in this article the structural design of the old doors of the Organ, which have to be placed again in their original position. But as in other historical projects, is always a good beginning to research similar cases that can give further information. That's why some cases were compared sharing same static conditions in order to find advantages to design a better structure using as less material as possible. Some static values were checked and compared, maintaining advantageous standards while doing the changes that were proved as positive to improve the new design of the doors.

Keywords

Prototype; doors; organ; wood; stress design; Cathedral of Tarragona; restoration.

Introduction

At the beginning of last march we hoisted up a great dimensions cross in the interior of the church of Santa Maria del Mar of Barcelona (fig. 1). It was a complicated and stressful project because the cross - made of bronze and weighting 10 kN – had to be sustained by the existing ceiling vaults of the presbytery. Although the calculations and inspections were overwhelmingly positive and enough guaranties could be made to continue the project forward, nobody was able to breathe a sigh of relief until the cross was completely suspended from the central cable, hanging a span from the ground for a few seconds.

All along the months that the project went on -of which we made the technical supervision- all the members of the team thought that it was a strange commission, but at the same time the most extraordinary that we will ever be part of. To our surprise, few days later, we received the commission from Archdiocese of Tarragona to participate in the renovation-restoration of the doors of the Organ of the Cathedral (fig. 2) in a multidisciplinary team directed by Centre de Restauració de Béns Mobles de Catalunya – CRBMC. Our Job would be to test or design the structural elements of the doors and to ensure the viability of the suspension.

The doors. Antecedents

Our enthusiasm to start was immense, especially by the fact that it was not any ordinary building and that the intervention was not only a simple examination of an existing element but a collaboration with a team to return the doors to the great Organ, improving, if possible, the existing structural system if any risk is detected.

The doors of the Organ – from XVI century - are painted canvases of large format fixed on wooden structural frames with hinges that could be closed or opened to leave it visible, situated in the central nave of the Cathedral of Tarragona. There was a liturgical and very symbolic tradition that in the Lenten season the Organ would be closed, coinciding with its silence, until after the resurrection Sunday, when it was opened and played again.

The doors were removed some years ago, in order to renovate the interior of the cathedral and the pipe organ, and no documentation was kept. Until the beginning of the intervention they were left lent over a wall until the moment that it was decided to restore and place them in their original position. The state of the wood is very poor, regardless no decision would be made about the intervention until it is possible a deeply analysis. But this fact has motivated this study, based on a real case and situation, even if the conclusions may not be used at the real project and intervention (fig. 28).

The doors. Current state

The doors consist of rectangular perimeter frames - base of 4.6 m and height of 7.0 m – with a system of posts and diagonals that give it structural rigidity. On both interior and exterior faces are located the painted fabric, nailed to the frame and which would probably have a structural function besides the picturesque one. The doors are mounted on the furniture of the Organ via wrought iron hinges (5 each door) that enter more than 1.5 m inside of the frame.

// **Design of a prototype for the doors of the Cathedral of Tarragona**

Figure 1.
Hoisting up the Santa Maria del Mar Cross.
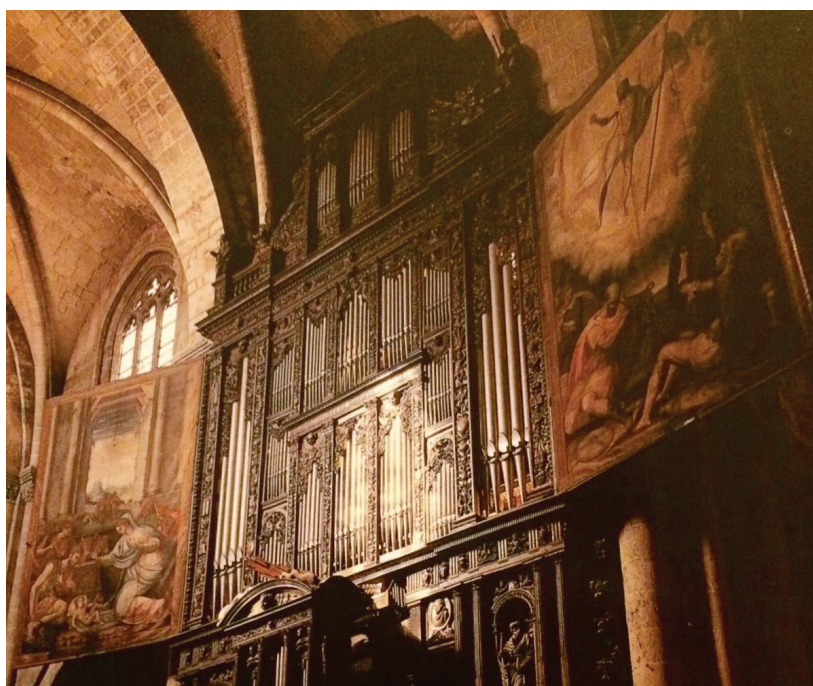
Figure 2.
The doors of the Organ of the Cathedral of Tarragona.

Figure 3.
The pipe organ without the doors

Figure 4.
The pipe organ without the doors.

Figure 5.
The supporting scaffolding of one of the frames.

Figure 6.
The supporting scaffolding of one of the frames.

Figure 7.
The state in which the doors were found.

Figure 8.
The scaffolds as a door support.

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One of the facts we gathered in the displacement of the first door to the provisional scaffolds was the weight of each element. Its weight, 2.16 kN, included the linden wood structure, the fittings and joints of the 5 hinges, the two canvases (interior and exterior) and thousands of nails with wide heads by which are fastened to the frame. This information is very important since, first of all, it enables us to know the maximum forces on supports of the anchors of the hinges (vertically as much horizontally) and in second place it gives us an approximation of the weight of two canvases, about 70 m2 each frame. The first exercise consists of subtracting from the total weight of 2.16 kN, the weight of the wooden structure and the fitting of wrought iron. The resulting value would be the weight, more or less precise, of the canvases and the fastening nails. This weight will be practically the same one that the new frames should support.

One objective which we have focused on and planned for from the beginning was to try to not alter the system technically, ensuring to copy the pre-existences and to add the minimum of modifications for improving substantially its behaviour. A clear example is the selection of the type of wood: Linden wood on the existing frames. This is a sort of wood of large and straight spans, but soft and with sap rich in minerals and nutrients, which make it very vulnerable to degrading agents and with little durability. It is proposed for the new prototype American or Canadian cedar, which is resistant to decomposition but not so easily degradable by Xylophagous insects.

The choice of the wood is still an open decision. Aluminium frames and hybrid aluminium-wood frames are common but options that we discard for now, and the first tests are being done with C18 type wood (conifer with resistance of 18 N/mm2 under normal stresses) and density of 4.20 kN/m3.

Other important elements to consider and to have in mind are the five hinges which fix the frames to the organ. They are made of wrought iron, are 150 cm long and weight 1.2 kN each (6.0 kN in total, by no means negligible).

With all these weights and subtracting them of the total, we have around 0.5 kN for each canvases of 35 m2. It is important to consider this weight, first for being a permanent load, which are the type that cause greater deformation in wooden structures, and second for its non-uniform disposition, because it has a greater percentage at the superior part of the stretcher and almost zero at the inferior part.

One of the wonders of the doors is its system of opening and closure. It is a manual mechanism operated by a handle - situated on the inferior bench of the organ – which rotates a roller (image 11) joined by the two heads of a continuous cable which, according to the direction of rotation, opens or closes the frames. An ingenious system of pulleys and bearings (image 12) which has been repaired and enhanced in diverse recent proceedings, with some changes in the materials but maintaining the same initial essence, and which use is now intended to be recovered. This is a good new, but an additional constraint added to the assembly which has to be taken into account since it has not been used in many years.

Figure 9.
Inferior hinge of the frame.

Figure 10.
Image of the bad condition of the frame.

Figure 11.
Inferior roller of manual operation for opening and closing.

Figure 12.
Arm with bearings which pushes or pulls the doors.

Design of a prototype for the doors of the organ of the Cathedral of Tarragona

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The doors. Technical inspections

The structural verifications are focused on two aspects, primarily: the verification of the anchoring of the hinges to the fixed furniture of the organ, and the dimensioning of the frame structure. Indirectly they lead to diverse non-structural decisions which are also important and linked to the structural behaviour of frames: the stress on the canvases and the possible creases of the doors, the bad functioning of the closing and opening system due to the excessive deformation, the vibration or the instabilities due to the movement and the excessive slenderness, the fitting of the doors inside the furniture of the organ… are some of the examples. From here the actions and the decisions have to be taken collectively, following multidisciplinary criteria, since one issue affects diverse and very specific fields and none of the members of the team controls transversally in its totality. This is what makes this project a very exciting challenge and at the same of a great exigency for all those involved.

The existing frame is a light structure, orthogonal, modulated and orderly with a perimeter rectangular framework, two vertical posts and three interior horizontal elements, in addition of two diagonals. All of them are 4x12 cm, linden wood in a very bad conservation state. This reduced thickness makes the slenderness more extreme, with elements with base of 4cm and height of 700cm in the transversal direction, the movement direction.

The details of the joint and intersections between the bars are unknown, because until this moment, the paintings of canvases have been restored on the old frames to avoid folding them during the weeks that the project of designing and assembling of the frames lasts. This has limited the analysis of the structure of the frames.

By palpating and in backlighting the geometries and the dimensions has been extracted to elaborate a sketch of the image (fig. 14) which has been the base of its analysis, and which we will consider an approximation from which we can start the analysis. In despite of its geometrical proximity, it will never be enough similar to the real behaviour of the system, because we don't know the typology of the joints, its rigidity and the participation of the canvases and the hinges among other things.

A first analysis of the deformation and stresses behaviour has been done with the program WINEVA, chosen for its clarity and easiness of data input, foreseeing the realization of different families of models to be able to compare the results.

Technically the values which has been chosen as notable, starting with the distribution and the direction of the reaction on the furniture of the organ (fig. 15) or the instantaneous maximum deformation of (0.8 mm – fig. 17) are the maximum compression in absolute value (2.35 kN – fig. 16), the maximum stress under compression (0.49 N/mm2) and the maximum value of horizontal reaction. Furthermore, these are the moments and maximum shear forces (which help to know if there is an over-solicited element) although a priori they don't affect the global behaviour of the frames in a notable way (fig. 18 and fig. 19).

Other results have been analyzed, but these are the values that are chosen as a reference with the intention of reducing the maximum values, without increasing the inherent weight (the major permanent load of the system).

Figure 13.
Image of initial state of the first frame.
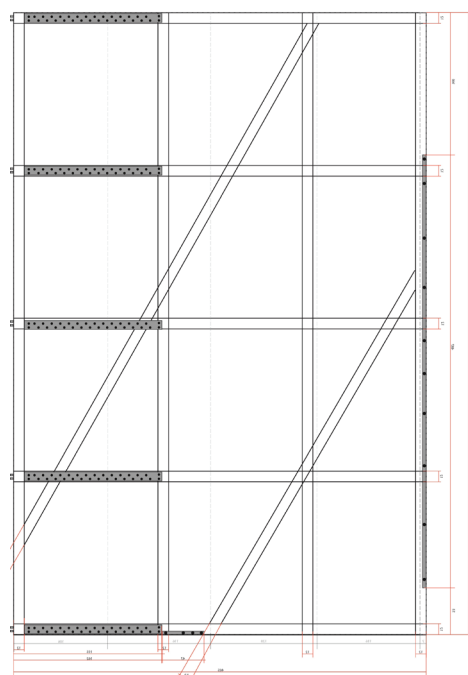
Figure 14.
Initial sketch done by the restorers.
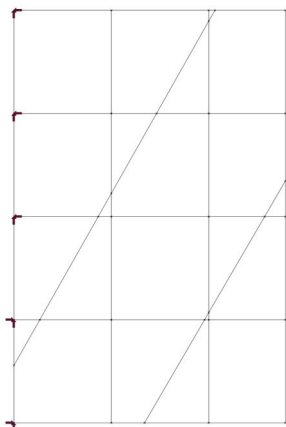
Figure 15.
Reactions of the frame.
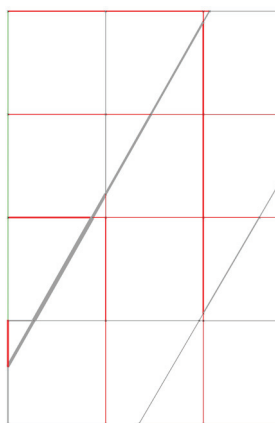
Figure 16.
Diagrams of the frame.
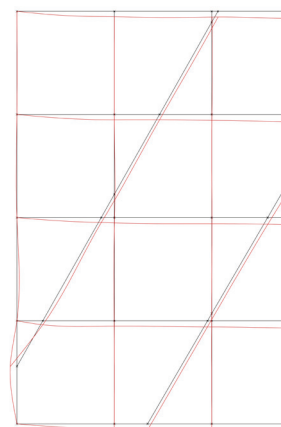
Figure 17.
Deformation of the frame.
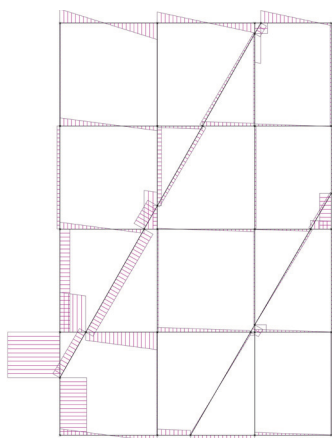
Figure 18.
Diagram of shear forces of the frame.
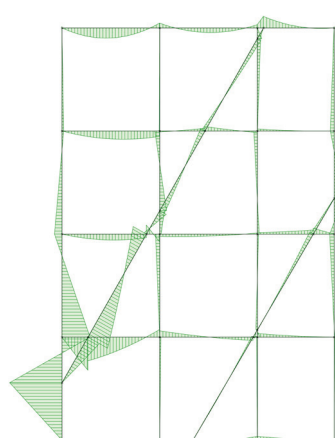
Figure 19.
Diagram of bending moments of the frame.

Figure 20.
Diagram of maximum global stresses of the frame.

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Analyzing more particularly the previous images, it can be seen that the point of rotation of the frames is situated between the third and fourth hinge, encountering the maximum reaction in the fourth hinge, a position near the diagonal with the maximum of compression. The disposition of these encounters between the bars seems little accurate, since it ends up causing the maximum of shear forces and bending moments, which accumulate the maximum stresses (fig. 20) in the bars not considered as principals.

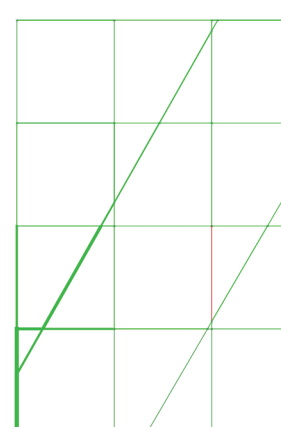An effect that will be favourable but has not been taken in consideration in this phase of analysis is the structural effect of the hinges in the left part of the frame on a resistant level. It has been taken in account, logically, their inherent weights, but the horizontal elements which they are anchored have been considered of sole wooden material.

The collaboration of the canvases as a structural element is unclear, although certainly they come under load and deform, they are tensed and help to maintain the geometry and distribute the stresses accumulated in the intersections of the wooden elements. Due to its conservation state, stiffening and tearing of some the extremes, no structural function is envisioned in the new design of the frames for the canvases, although they are a limiting condition, since if they deformation of the frame is excessive they will be tensed, something that cannot be permitted.

The doors. Similar cases

After some days of research, three cases of elements has been chosen that are considered to have similar structural characteristics - of loading and supports – to the case study.

The three cases are of doors, or doors of altarpieces of diverse dimensions, but with similarities that permit us to analyse with same criteria as in the actual frame of the doors of the organ of Tarragona and to see if they have some logic in structural design that could be used in the new design in order to improve the actual conditions.

The three cases considered are:

1. A solid wooden door located in the abbey of Saint Pierre de Moissac (Occitanie, France).
This is a secondary door of the premises, solid, wooden with a very clear disposition of posts and diagonals, and the inferior part has a double thickness (fig. 21). It has been considered for trebling the compressed diagonal, and duplicating the superior horizontal tensed element, with the idea of distributing the stresses in different parallel bars. It disposes of two hinges.

2. The doors of the major altarpiece of Church of San Miguel Arcángel d'Ibdes (Calatayud, Zaragoza)
This is one of the closer case and more similar which has been found. Constructed in 1556, they dispose of minor density of structural elements (fig. 22). Their restoration by IPCE (Instituto de Patrimonio Cultural de España) has been finalized in March of 2017.

3. The doors of major altarpiece of the church of San Pablo (Zaragoza)
In the same manner of the one from Ibdes, it is one of the closer and more similar cases that has been found. Constructed in 1524, its structure of diagonals disordered inside of a frame with certain modulation is notable (fig. 23). They were restored some years ago by IPCE (Instituto de Patrimonio Cultural de España), reproducing the same original frame.

The prototype. Structural analysis. Comparative cases

Once the cases for comparison are chosen, it is needed to homogenize some of the particular properties, like the dimensions, the applied loads or the number of the supporting hinges, among other things. This is a first phase of adjustment in which specific data of original case is lost for approximating toward the case study, to be able to compare some parameters and results from a more objective point (fig. 24).

Thereby, the dimensions of the frame and wooden elements were adapted to the doors of Tarragona, and the weight of the canvases and the hinges were unified (elements that are thought to be preserved). A geometrical adaption which still has not been done in this first phase is adopting the geometry to the exact position of the five hinges of Tarragona, since its position is linked, usually, to the position of the horizontal inferior elements. Modifying the position of the five supports, would alter excessively the models to be comparable. The objective is to compare the real behaviour with dimension and similar loads, but without adapting fully the bars to the fixed points of another case which would make them loose essence. This will be undertaken in the second phase.

The first verification that has been done, before a more profound analysis, is the comparison of the inherent weight of the 4 models. Being a permanent load, in a displacement with variations of humidity (equal to a class 2) the weight is needed to be more similar between the models, in the way that the one that has more density of interior bars, these would be of minor section. The resistant characteristics, the density of the wood and the dimensions of the frameworks of the frames are the same in the four models.

On the subject of the joints, and looking to unify criteria, the exterior frame is articulated to the four extremes and so are the bars that reach it. It has to be taken in account that the frame of Tarragona has only 4 cm of thickness, and that the intersections imply a major weakness of the element, in the way that the links between the elements that are not straight come close to the behaviour of a pure articulation. In a more advanced phase it is intended to adopt the geometry so there would not be intersection of more than two bars, which would make the link impossible.

Also, the values of the horizontal reaction on the hinges have been compared, to estimate the points and the values of maximum solicitation. The Tension-Compression values of reaction are not representative in our case, since they produce the same effect on the furniture of the organ, by being doors that could be opened up to 180°.

The next result table compares different parameters, where the maximum value of each row of results with the four compared models is indicated with bold font.

In the table (fig. 25), it is verified that the model of the existing frame of Tarragona is the one that accumulates the most maximum values, being of notice is the instantaneous deformation for the relation of the behaviour with the patrimonial canvases (about the double of the one in second place); the one with maximum stress under compression, which could provoke instabilities (approximately the double of the most favourable one); the one with maximum stress for the bending moment, which gives us an idea of the effectiveness of the design (four times bigger than the minimum value) or the maximum horizontal reaction, which demonstrates the effectiveness of the distribution of the loads on the supports (it accumulates the maximum value of compression and almost the maximum of tension).

Figure 21.
The door of Moissac.

Figure 22.
Placing the doors for dimensional verification. San Pablo.

Figure 23.
The doors of altarpieces of Ibdes (Zaragonés 2017).
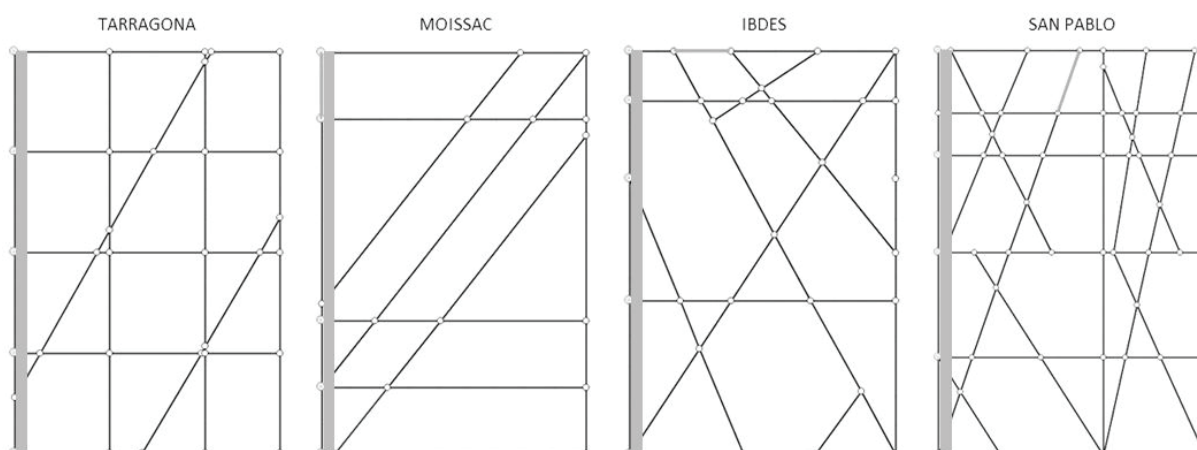
Figure 24.
Initial models (with real adapted geometry) which has been compared in the first phase.

		TARRAGONA	MOISSAC	IBDES	SAN PABLO
LOADS - kg	Ihn. Weight	124,20	113,10	122,90	130,20
	Hinges	48,80	50,10	39,00	48,80
	Canvas fabric	97,80	97,80	97,80	97,90
	Total	270,80	261,00	259,70	276,90
MAX. DEFORMATION - mm	Instantaneous	1,20	0,30	0,50	0,60
MAX. AXIL - kg	Compression	235,00	128,00	190,00	165,00
	Tension	88,00	92,00	88,00	70,00
MAX. SHEAR FORCE - kg		53,00	29,00	12,00	41,00
MAX. BEN. MOMENT - kg·cm		2.610,00	1.660,00	600,00	780,00
MAX STRESS - kg/cm2	Compression	4,90	2,67	3,96	3,44
	Tension	1,83	1,92	1,83	1,75
	Shear forces	1,10	0,60	0,25	0,85
	Bend. Moment	54,38	34,58	12,50	16,25
REACTIONS - kg		HORIZ	HORIZ	HORIZ	HORIZ
	Hinge 1	-50,50	-93,80	-64,70	-47,40
	Hinge 2	-23,30	-2,20	4,50	-8,20
	Hinge 3	-90,60	32,60	-15,30	-38,10
	Hinge 4	133,70	61,20	-17,50	-25,50
	Hinge 5	30,80	2,20	93,00	119,20

Figure 25.
Table of results of phase I.

Furthermore, if we analyze globally the results table, we would see the minor forces and stresses under compression, thus also less prone to suffer instabilities, and the minimum value of deformation in the 'Moissac' model. However, this model accumulates some high bending moments and, although the reactions are more homogeneous, it has room for improvement.

The two other models are the intermediate results with regard to the previous ones, highlighting the minimum of stresses of shear forces and the bending moment of the 'Ibdes' model, that indicate a more pure axial behaviour, or the fact that the design of the 'San Pablo' model with many bars with reduced section does not stand out for an excess of deformation or of stress. This last one is the only of the four cases with superior hinges under tension, with the point of rotation between the fourth and the fifth hinge.

The prototype. New frame. Initial proposal

The proposal of the new frame design has never been a closed question. The project of renovation-restoration from the beginning evolves as more information is gathered. To show respect for the encountered pre-existences and understanding that they have been resisting for some hundred years, it was deemed adequate not to dismiss maintaining the existing geometry although being of new construction and in all case seek to improve it, so it was included in this comparative study.

After the first analysis and verifying that the design of Tarragona is improvable concerning the geometry, and that the strategy of using the minimum of material is very favourable for the reduction of the permanent loads, it seems adequate to us to study variations in its geometry to improve its structural behaviour.

In this sense, the first phase of the analysis will be of great utility for facing the new design. It seems clear that the fact of disposing of diagonals in the compressed direction is a good option. It is helpful that they are compressed because the links will be easier to execute and elements or joining materials would not be required and furthermore because as they are more than one unit, it will divide and reduce stresses that could provoke an instability of the bar in question.

According to these commentaries, some first models are proposed (fig. 26), adapting the geometry to the position of the five hinges that require to keep the 5 horizontal bars of the Tarragon model, but some diagonals are introduced like the style of the 'Moissac' Model.

Analyzing, with the same criteria as on the first phase, the numerical results of the first models of this second phase, there has been proposed some variations, step by step, in order to be able to verify the effectiveness or not of each new proposal. In this phase, the weight of the canvases and the hinges are the same, and so is their position in the model. What is different is the inherent weight of each model (according to if it has more bars or not, since the dimensioning of the bars that are repeated are always the same, with occasional exception).

In the next results table (fig. 27) the parameters are compared like in the first phase, the maximum values are indicated with bold font:
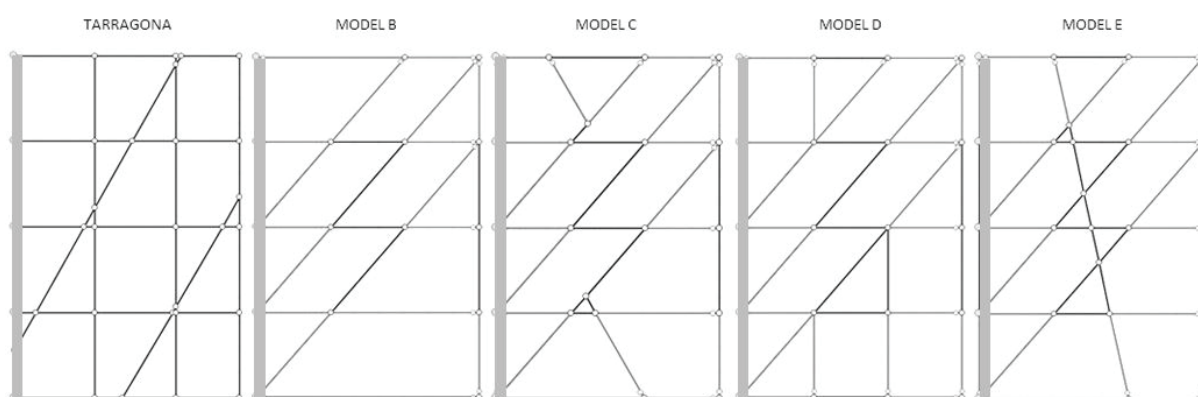
Figure 26.
Comparing geometries of the analyzed models.

		TARRAGONA	MODEL B	MODEL C	MODEL D	MODEL E
LOADS - kg	Ihn. Weight	124,20	110,20	115,00	117,20	1.26
	Hinges	48,80	48,80	48,80	48,80	0.49
	Canvas fabric	97,90	97,90	97,90	97,90	0.98
	Total	270,90	256,90	261,70	263,90	2.72
MAX. DEFORMATION - mm	Instantaneous	1,20	0,20	0,20	0,20	0,20
MAX. AXIL - kg	Compression	235,00	84,00	99,00	93,00	0.92
	Tension	88,00	62,00	79,00	69,00	0.79
MAX. SHEAR FORCE - kg		53,00	27,00	29,00	17,00	0.16
MAX. BEN. MOMENT –kg·cm		2610,00	1320,00	770,00	360,00	0.04
MAX. STRESS kg/cm2	Compression	4,90	1,75	2,06	1,94	19.17
	Tension	1,83	1,29	1,65	1,44	16.46
	Shear forces	1,10	0,56	0,60	0,35	3.33
	Bend.Moment	54,38	27,50	16,04	7,50	0.83
REACTIONS - kg		HORIZ	HORIZ	HORIZ	HORIZ	HORIZ
	Hinge 1	-50,50	-61,80	-39,60	-46,60	-0.40
	Hinge 2	-23,30	-46,50	-79,00	-68,90	-0.79
	Hinge 3	-90,60	33,70	40,50	33,50	0.16
	Hinge 4	133,70	26,40	16,20	24,40	0.53
	Hinge 5	30,80	48,20	61,90	57,50	0.50

Figure 27.
Table of results of phase 2.

According to this comparison, it is observed, at first sight, that the original model (Tarragona) accumulates the maximum values, notably – in a negative sense – being the one that weights the most, but with the worst design possible, as the value of maximum instantaneous deformation demonstrates (6 time superior to others); the one with the maximum stress under compression, which could provoke instabilities (force of more than double of the most favourable one); the one with the maximum stress of the bending moment, since it gives us an idea of the effectiveness of the design (more than seven times greater than the minimum value) or the maximum horizontal reaction, which demonstrates the effectiveness of distribution of the load on the supports (accumulates the maximum value so compression and tension).

The first model evolving as a result of merging the models 'Tarragona' and 'Moissac' (Model 'B') show very favourable results, since almost in all the parameters it achieves minimum values in comparison, notably minor stress under compression among all analyzed models and a more uniform distribution of reaction. It has a greater stress state in comparison with other models like shear force and bending moments – without being worrisome values – the design is still improvable.

Analyzing this model in detail, it is observed that the values of greater bending moment and shear force are concentrated in the horizontal superior and inferior bars, due to the inherent weight, of the hinges and canvases. It is decided to give more supports to these bars with vertical posts and diagonals of minor section (Models 'C', 'D' and 'E').

Figure 28.
Image in real magnitude of the furniture of the organ captured by drone (Octocam-maps).

Figure 29.
Team gathered with the topographer.

Conclusion

The bad condition of the wood of the frames implies, unfortunately, that it is necessary to substitute the totality of the bearing structure of the canvases. This fact open the door for a deep and accurate analysis of the pre-existence and to use new technologies for structural analysis to improve its functionality and to be able to apply 'science and research' in a project of patrimonial renovation-restoration of first order, as is this case.

Our first objective and main concern was to keep the canvases under stress and without creases, thus we had to find a design of frame that would limit greatly the deformation, to avoid that the patrimonial canvases could suffer deformations or excessive stresses, which would mean its potential degradation.

To be able to evolve and improve the design, some parameters have been set in comparison, like the dimensions of the frames, joints and loads. The same process of standardization has been done with the quantity, dimensions and positions of the interior bars, which have been also modified along the process.

The weight and other factors of the models have been homogenized to not disfavour or favour some over others. The presence of the hinges that could contribute in an increase of rigidity on the first part of the horizontal bar with which is connected has not been simulated.

The control of inherent weight, of the stresses under compression, which could result in instabilities and over stresses, and of the shear force and bending moment have resulted in an evolution of the design on the parts with most concentration of stresses. When these parameters have been stabilized, a more uniform distribution has been verified with lower values in the points of support. As a way of simplifying the process and the results, the coefficients of increasing of load were not applied, neither those which affect the deferred deformation or the characteristic resistance of the wood. Being coefficients that affect the same values in each model, they have not been considered in this comparative analysis, and they will be applied in the verifications of the final model, before its construction.

Once to the point of valuing the models, according to the results of the comparison realized, the keys to the good design for a frame of characteristics of the case study are the optimization of each of the bars, making them function at the best possible way (particularly and combined) without adding unnecessary inherent weight.

About the numerical results of the comparisons, especially of the phase 2, the best models for the purpose of results are 'D' and 'E', with minimum variations between them. Probably, valid now, might be a constructive reason to tip the balance towards the model 'E', for not having intersections of more than two bars. Its final definitive selection is discussed with all the team, especially with carpenter, in a date posterior to the closing of this article. What is described in this document is methodological procedure of looking for the optimize form on a theoretical level according to constraints of the construction work.

Design of a prototype for the doors of the organ of the Cathedral of Tarragona
Jordi Payola Lahoz

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The tale of the miracle of Duisburg: A miracle or an illusion

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The tale of the miracle of Duisburg: A miracle or an illusion?

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Abstract

On October 2008, the biggest mosque in Germany at the time was opened in Duisburg's Marxloh district. In addition to its size, what distinguishes this building from other mosques in Germany was the lack of protests against the construction of this building. For this reason, the mosque is also referred to as "the miracle of Duisburg". The reason construction of the Marxloher Merkez Mosque went so smoothly was due to the participatory approach that the city government adopted during the planning process. The representatives of the Turkish community, German politicians, church and community leaders were all invited to contribute to the mosque project early on. The mosque did not become a symbol of social division in Germany but rather a symbol of religious, cultural and social interaction ("The Miracle of Marxloh: Bringing a Community Together around a New Mosque", 2008). This paper presents the success story of the DITIB commissioned Maxloher Merkez Mosque. Through this analysis and a theoretical framework based on the notion of visibility, I aim to investigate the factors that contribute to the successful reception of the mosque by the public. I theorize that three factors enabled this positive reception of the mosque. These factors are: (1) the architecture and urban design process of the mosque, which was a participatory process bringing many different actors together (2) local context, which contributes to the visibility of the mosque and (3) the politics of visibility which was framed through the self-presentation and the reception of the mosque by the media. I argue that although the Marxloher Merkez Mosque project is perceived as a successful project that managed to overcome the risks associated with social conflict, this "Miracle" of Duisburg only provides social cohesion on the surface and leads to "self-orientalism" and further alienation.

Keywords

Mosque; Duisburg; Marxloh district; participatory process; miracle.

1. Turkish Diaspora in Germany and the Mosques Beyond the Visibility-Representation Nexus

Today, wherever one looks, Islam - and whether it belongs to Germany or not – stirs a heated debate ("Is Islam Changing Germany", 2017). Before 2015, Germany had already been home to over 4 million Muslims, most of whom came from Turkey after World War II. Even before the start of the contemporary refugee crisis, the debate on Islam and its place in Germany was framed around a Turkish population that had not been well-integrated into the German society. Today, many Turks prefer to live in social (and spatial) enclaves within big cities, where the dominant language is Turkish rather than German and attend mosques that are operated by Türkisch-Islamische Union der Anstalt für Religion (DITIB - Turkish-Islamic Union for Religious Affairs), an organization linked directly to the Turkish Government Authority for Religious Affairs (Su, 2017). This involvement of the Turkish government - and its self-defined role as the administrator of Islam in Germany - has been shown by scholars and politicians as one of the most important factors preventing Turkish Muslims from integrating into German society (Kern, 2017).

The involvement of the Turkish government in the administration of Islam is closely related to the legal status and accommodation of Islam in Germany. European nation-states' handling of Islam, the minority religion, differs substantially as the institutionalization of any religion builds upon the pre-existing patterns of church-state relations (Bader, 2007; König, 2007). Especially in Germany, compared to other European nation states, the institutional position of Islam is very underprivileged. Christian churches and Jewish synagogues in Germany have formal status as corporations according to public law. This status allows them to profit from the taxes collected by the state. As Muslims living in Germany do not have such an organizational structure, German authorities do not grant Islam the same legal status (Fetzner & Soper, 2005). For this reason, Islamic organizations in Germany remain disadvantaged compared to the established churches as they lack legal recognition and financial support (Fleischmann & Phalet, 2012). Nielsen (2004) explains the operational structure of Islam in Germany. Since Islam is not a formal religious community recognized by the state, the religious associations operate under the category of registered associations (eingetragener Verein, e.V.). Unlike the Jewish, Catholic and Protestant communities that work closely with state authorities and are included in the decision-making process in the areas of education, welfare and health, the lack of a legal recognition prevents Islamic associations from taking part in the policy making process (Tol, 2008).

Although the Turkish government has been sending imams to Europe since 1975, it was not until the establishment of DITIB in 1984 that efforts to organize the religious life of Turkish immigrants took effect (Pederson, 1999, p.26). DITIB denies links to any official or private organizations and defines itself as an independent umbrella organization, however, it is the Turkish government's extension for religious affairs abroad and relies on financial support from the Turkish government. DITIB works under the Directorate for Religious Affairs, which is a part of the Turkish prime minister's office. The organization is responsible for delegation of imams and employees abroad ("Hakkımızda", 2017) and these employees have the status of civil servants of the Turkish Government (Tol, 2008). The imams are sent abroad temporarily and replaced every four years.

DITIB functions through 14 state level organizations and 930 registered cultural associations (e.V.) that also act as mosques and follow the official Turkish view of Islam ("Hakkımızda", 2017). Being the largest structured Islamic organization, DITIB serves as the main administrator of Islam in Germany. The role of the Turkish government as a major religious organizer in Germany has served to further

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alienate an important section of the Turkish immigrant population who still lack basic citizenship rights despite their long presence in the country. Because Turkish immigrants do not have the right to vote unless they have acquired German citizenship, Islam and Islamic organizations have become the only platform to voice social grievances within German society (Tol, 2008). Within this context, mosques mark the unmistakable presence of Islam in Germany.

Despite the deep involvement of the Turkish government on the administration of Islam in Germany, mosques within this context cannot be equated with their counterparts in Turkey as the transformation of Muslim communities followed different historical and social paths in each country (Göle, 1999). Although the design of mosques in Germany is heavily influenced by trends in Turkish mosque architecture, the meaning and use of the mosques differ substantially in these two contexts. While mosques in Turkey only serve the purpose of religious practice, their counterparts in Europe become social and physical spaces where Turkish immigrants can organize around a common identity (Tol, 2008). Muslims in Europe often redefine themselves as minorities which in turn changes the religious practices and subjectivities of Muslims and repositions them in secular Europe. From the point of view of certain European collectives, this process is far from a quiet process of immigration, adaptation and accommodation and the increasing Islamic presence in public life changes their collective memories and self-perceptions. Islamic signs and symbols in the European landscape become more and more visible, and become major sources of cultural and political controversy. Disputes surrounding the increasing visibility of Islam in the urban landscape through the construction of diaspora mosques signals the reterritorialization of Muslims and reveals how the European public deals with cultural and religious difference (Göle, 2011, p.383-384). This visibility of Islam is occasionally seen as shocking and shifts the public discourse from social and economically related problems to religion and citizenship issues. It is exactly this visibility of the purpose-built mosque that makes it the material symbol and center for conflict over whether Islam can ever be a part of European public life (Landler, 2006).

With the increased visibility of mosques in European public space over the last three decades, the conflict over the place and meaning of mosques stems from the politics of visibility (Göle, 2011; Jonker, 2005; Bowen, 2007). Muslims in Europe have started to move from their private backyard mosques to the visible public cultural frontiers of society marked by increased mosque construction activities in the late 20th and 21st centuries (Becker, 2017). In the past, the religious activities of Muslims in Europe were confined to invisible and private prayer rooms, while today mosques publicly and visibly mark the presence of Islam (Es, 2012). The public visibility of Muslims is informed by negative cultural associations related to Islam (Fekete, 2004). Cheng's research on the discussions of minaret bans in Swiss parliament shows how these negative feelings attached to Islamophobia combines with national identity (2015). Islamophobia has been analyzed through paradigms of radicalization to explain cultural differentiation between Europe's Muslim religious minorities and its mainstream (Becker, 2017; Bayoumi, 2006; Elver, 2012; Meer, 2013). According to recent studies, the fear of Islam and Muslims among certain European citizens stems from a number of notions: presumed failure of prioritizing democratic values and ideals (Tyrer and Sayyid, 2012, Romeyn, 2014), different and unequal understandings of gender (Ewing, 2008), perceived ethnic differences (Khosravi, 2012) and expected inclination towards extremism (Fekete, 2004). In media, representations of Islam are dominated by these notions, creating a "publicly available" and shared grammar that might be understood as equating Islam with threat (Becker, 2017, p. 4; Said, 1981; de Galembert, 2005, p. 190).

Although for Muslims, a mosque with its dome and minarets is not only a place of worship but also a cultural space of religiosity and sociability that is reminiscent of a familiar landscape, Göle refers

to the "loss of innocence" of the mosques. Politicization of the mosque, especially after the 1979 Revolution in Iran, from where the revolutionary fervor spread, made mosques visible sites for the contestation of urbanism, pious politics and political Islam. In other words, mosques as religious public spaces cannot be confined to the boundaries of its community of believers. The mosque claims its visibility both in national and global contexts, contesting the existing separation between private religious and secular public fields; "between personal piousness and secular publicness" (2011, p. 384). To conclude, mosques and their visibility signify a process of spatial transgression of Muslims into the European public which contests the secular and cultural norms of the host country. In this context, Islam does not only cross the geographical boundaries through immigration but also transgresses the invisible cultural borders of the European public space.

The following case study of the Marxloher Merkez Mosque shows the complicated notion of visibility, demonstrating how the public staging and performance of mosques within the local context can encourage inclusion and integration. The public reception of the mosque determines not only who is seen, but also how they are perceived (Becker, 2017). I argue that public acceptance of the mosque into the mainstream depends upon three factors: (1) the architecture and urban design process of the mosque, performed by the actors that take part in the process, (2) the local context in which the mosque is built and (3) the politics of visibility, which relates to how the mosque project was framed by the media and presented by the mosque organization itself and effected by their communication with the mainstream society.

2. The "Miracle of Duisburg": Marxloher Merkez Mosque

Marxloher Merkez Mosque, designed by the Turkish-German architect Cavit ahin, is a much more direct depiction of the Ottoman style compared to other Turkish mosques in Germany. The external structure of the mosque is dominated by a dome structure that includes a central dome and four half-domes around it (fig. 2). The entrance hall is covered by five small domes placed relatively lower than the level of the central dome structure. The 23-meter-high dome is complemented with a single 34-meter-high "pencil form" minaret typical of the Ottoman period (Korn, 2013, p.38).

Inside the mosque, there is a 40x28m praying area surrounded by a second-level mezzanine (Korn, 2013) (fig. 3). This second level mezzanine, mahfil, is reserved for the use of women for daily prayers and at important religious days, when attendance to the mosque by the congregation is much higher, it used by the men. The prayer room can accommodate 1200 people, 800 in the main prayer area downstairs and 400 in the women's section upstairs.

Due to its foreign style, the mosque stands out from the rest of Marxloh's urban landscape with its minaret and ensemble of domes and half-domes. Although mosques are becoming a more familiar element in German cities, according to Gorzewski three characteristics of the Merkez Mosque make it a unique one (2015). The first feature is related to the size of the mosque. At the time of its opening in 2008, Merkez Camii was the largest mosque in Germany with its 23-meter-high main dome and 34-meter-high minaret and its 1200-people prayer room. The event rooms and secondary rooms can also be used as prayer spaces for prayer during the celebrations of Ramadan and Eid, increasing the capacity of the mosque.

Figure 1.
Location of the Marxloher Merkez Mosque: a) (Ehrkamp, 2002) b) (Google Maps).
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Figure 2.
Marxloher Merkez Mosque (Baukunst, 2017)

 The second characteristic of the mosque is related to the double character of the building, serving both as a place to practice Islam and as a community center. Although both of these functions are accommodated within the same space, they are run by organizations independent from each other. The community center is accessed via the Warbruckstraße, while the mosque can be reached from the other side of the building. The building has a total usable area of 2500 m2, 55% of which is used by the DITIB mosque organization for praying and the rest is attributed to the community center. While the community center functions to promote interfaith dialogue, it also serves as a community center for the local Turkish population, offering homework support for students, language courses and intercultural seminars (Gorzewski, 2015). This establishment the mosque as an educational and meeting place along with its religious functions, signals the opening up of the Turkish community and Islam to the general population (Yılmaz, 2010).

The third characteristic of the mosque that sets it apart from other mosque projects in Germany is related to its funding. The 7.5 million Euro budget of the construction project was equally shared between donations made to the local DITIB and the EU and the state of North Rhine-Westphalia (NRW) (Yılmaz, 2010). Due to the fact that the construction of the mosque was financed partially by the subsidies of NRW and the EU (especially for the community center), the mosque project became one of the very few projects undertaken by an urban development agency (Winkel, 2012). This is very interesting considering the underprivileged position of Islam compared to other religious organizations. Since Islam is not legally recognized by the German government, to overcome the legal issues the construction of the mosque was funded by DITIB and donations from the congregation while local authorities and the EU incorporated the project into the urban and regional development plan and funded the construction of the community center (Topçu, 2009).

As one of the largest construction projects of DITIB, the Merkez Camii has a long history. Marxloh is characterized by its high immigrant population which is predominantly Turkish. Out of 20,500 people living in Marxloh, it is estimated that 13,500 of them have a Turkish background (Uslar, 2017). The Turkish influence in the neighborhood can also be seen from the neighborhood's main business streets which are dominated by Turkish hairdressers, döner shops, bridal wear shops, etc. In Marxloh alone there are over 10 mosques (41 in Duisburg), most of which are backyard mosques or mosques that were transformed from unused shops/apartments that are hardly recognizable from the outside. These small mosques and prayer spaces were regularly overcrowded on public holidays (Gorzewski, 2015). The situation was no different in Marxloh, the former DITIB mosque was established in an unused cafeteria space, which was not very favorable for religious use (Jenker, 2008) and was becoming inadequate for the use of approximately 500 households (Ehrkamp, 2007). The local DITIB was active in the area since its establishment in 1984, and decided that these makeshift prayer rooms were too small and they needed a new building.

In 1997, DITIB proposed the construction of a classical Ottoman style mosque with the support of the local Turkish community. As stated by the former chair of DITIB, Mehmet Özay: "Turkish people, who have been here for 40 years, have not seen a single dome and they wanted to see a dome again" (interview with Özay in Gorzewski, 2015). Being aware that such construction projects may become a source of anxiety in the district, the association's board of directors in Marxloh sought for cooperation with local administration, the Duisburg Development Union (der Entwicklungsgesellschaft Duisburg – EG DU), churches and other institutions. By 2002, an advisory council for the project was established with representatives from political parties, churches, local associations, neighborhood residents and businesses (Topçu, 2009). The ultimate aim was transparency and openness. Many meetings were organized for local residents and many critical questions were

raised. During the construction phase alone the project received 40.000 visitors, who wanted to learn more about Islam and the Muslim population of Marxloh. Although in 2006, this friendly and peaceful process was clouded by media reports on the involvement of the construction company's members in right-wing circles, the incident was almost forgotten by the time the mosque was opened in 2008 (Gorzewski, 2015). Despite these problems related to its administration, Merkez Camii still functions as a religious, cultural and social meeting place, and continues to provide educational and interfaith dialogue programs to bring together people from different backgrounds.

3. Discussion: The miracle of Duisburg or an illusion of miracle

Today, in Germany, the increasing number and visibility of mosques has become an undeniable phenomenon. The minarets of the mosques have started to join the cathedral towers and high-rise buildings in the German landscape and become a part of the urban silhouette. So far, this paper has presented the story of the Marxloher Merkez Mosque, located deep in the belly of North Rhine Westphalia, which presents an exceptional example of how Muslim identity became compatible with the German mainstream. Here the actors included in the design process accomplished a politics of positive visibility through three main factors.

The first factor that contributed to the positive visibility of the Marxloher Mosque is related to the local context and architecture. Although the mosque is much larger compared to other Turkish mosques in Germany, physically it remains quite invisible due to its location. Being located in an isolated area inhabited by a Turkish majority population undergoing a rapid urban decline contributed to the lack of public reaction (Alder, 2008). Compared to the DITIB commissioned Yavuz Sultan Selim Mosque in Mannheim that was constructed in 1995 and located in a central area which would provide high levels of urban rent (Figure 4) (Gorzewski, 2015), the seemingly unprofitable location of the Marxloher Merkez Mosque did not raise any questions from the public. Furthermore, the architecture of the mosque become symbolic of openness and transparency, thereby contributing to the positive public reception. The mosque provided transparency through very large windows on its façade, a detail that diverges from the traditional Anatolian style. "This is not typical of a mosque and it should provide transparency and openness" (interview with Mehmet Küçük in Gorzewski, 2005). Unlike disputes over the architecture of Cologne Central Mosque, whose dome and minarets would symbolically cast shadows over the Köln Dom (Figure 5) and whose central location would start a process of "ghettoization" of the neighborhood (fig. 6) (Becker, 2017). The construction of Merkez Mosque in Duisburg became an exemplar project showing successful communication between the builders, the city and the public, which can also be seen from the lack of resistance and reservations from the local German population, making the mosque "the miracle of Marxloh".

The second factor that made the Marxloher Mosque a successful project is related to its design process. According to Küçük, the participatory work of the advisory board, the "transparent funding" and the endorsement of the project by different parties created a friendly atmosphere and a sympathetic attitude around the construction project, in contrast to the ongoing mosque project in Cologne, Ehrenfeld (Gorzewski, 2005). According to Becker, during the design process of the mosque, neither a clear leader came forward to present the mosque project to the public, nor did the planning board engage in public debates to address to the public concerns that might arise from perceived differences (extremism, ethnic exclusion and the role of women). Becker (2017) even addresses the difficulties she encountered related to the "opaqueness" of this design process while researching. She failed to find any information related to the controversy around the Cologne
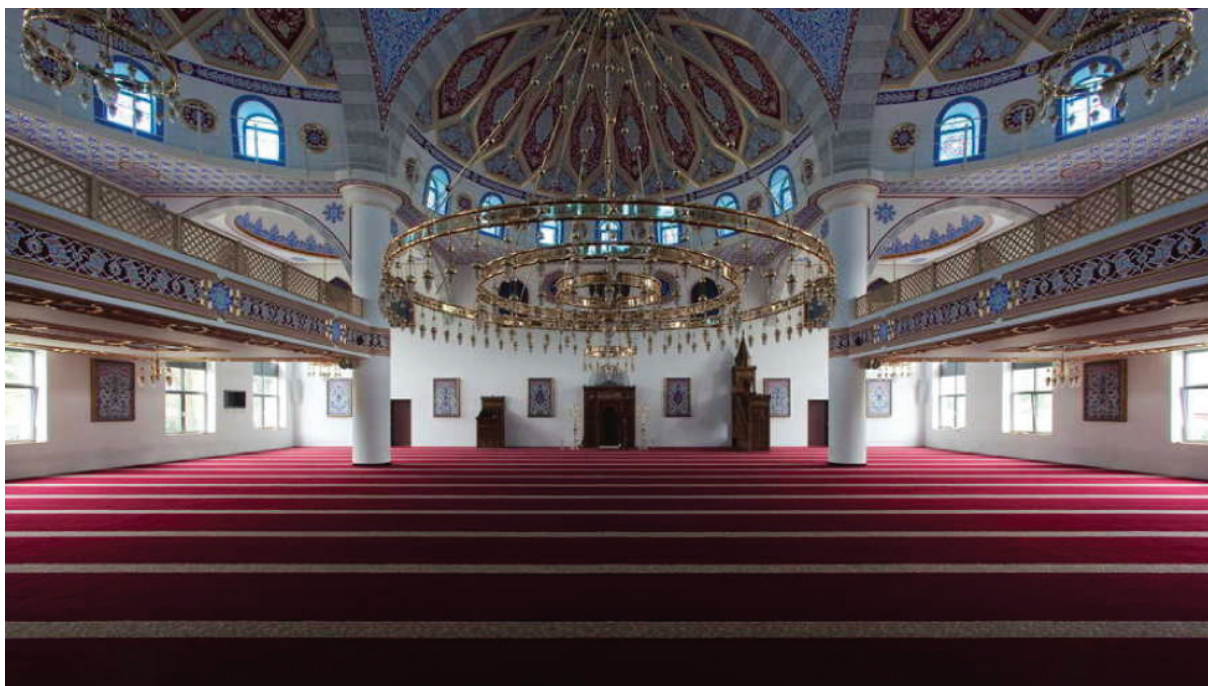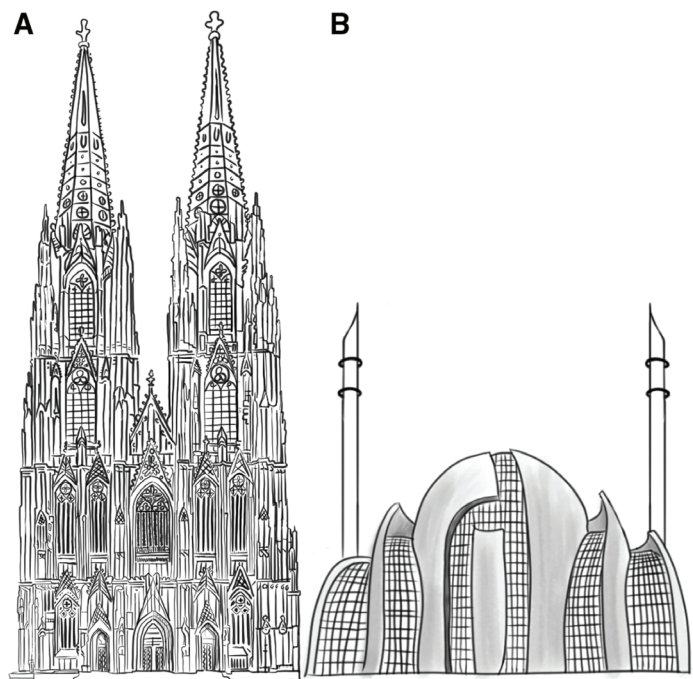
Figure 3.
Marxloher Merkez Mosque (Poolima, 2017)

Figure 4.
Yavuz Sultan Selim Mosque (Ditib-ma, 2017)

Figure 5.
Cologne Central Mosque.

Figure 6.
Sketch portraying Cologne Central Mosque (B) size in relation to Cologne Cathedral (A) (DGB Köln, 2010).

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Central Mosque and whenever she could, the failure of the mosque was blamed entirely on outsiders, especially on the architect, Paul Böhm who was dismissed as the project construction manager in 2011. As can be seen, while the participatory design process of Marxloher Merkez Mosque made it a successful one, the reluctance to include representative actors from different segments of the community caused the failure of the Cologne Central Mosque.

The last factor that contributed to the social cohesion framed around Marxloher Merkez Mosque is related to the media reception and self-presentation. At the time of its opening, city marketing also contributed to bringing the community together by a media campaign and the slogan "Made in Marxloh" referring to the participatory planning process that brought different coexisting groups in Marxloh together (Winkel, 2012). Although the reaction that Merkez Camii received from the public and politicians was a positive one, as mentioned before this peaceful process was shadowed by the conflicts within the mosque association itself in the later years. The rising conflict between conservatives and liberals in Turkey also caused tension within the Turkish diaspora in Germany and the mosque association itself, resulting in the resignation of the chairman of the mosque association, Özay, and dismissal of the press representative Küçük in 2009. Özay's view of liberal Islam was criticized extensively by the conservative group within DITIB (Gorzewski, 2015). By 2010, DITIB declared that the conflict within the administration was settled (Klinkhardt, 2010). The effective staging and performance of civic ideals – loyalty, participation and transparency – in the case of Marxloher Merkez Mosque highlights the absence of these ideals in the case of Cologne Central Mosque even more. By being open about the disputes even within the advisory board of the mosque and its transparent self-presentation, the design process did not encounter much negative reaction from the media and public.

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Conclusion

Although the Marxloher Merkez Mosque project is perceived as a successful effort that managed to overcome the risks associated with social conflict, I argue this "Miracle" of Duisburg only provides social cohesion on the surface and leads to what Batuman defines as "self-orientalism" (2016). With its distinctive architectural style, transferred from the Ottoman tradition, the mosque stands out in the urban landscape, working as a signifier of the Turkish-Muslim presence in the area. The architecture of the building with strong references to 16th century Ottoman mosques has major implications for the people living in the area. For the Turkish people, the mosque connotes a Turkish-Muslim identity, not a Turkish-German one and due to its performative nature, the mosque causes Turkish people to identify themselves with their old Turkish and Islamic characters, not with the Turkish-German identity which was aimed to be achieved through integration, resulting in a self-othering process. In this way, rather than becoming a symbol of integration as intended, it remains a representation of Turkishness, causing Turks to identify themselves as others in the Marxloh landscape. The other implication is related to the perception of the mosque by the German population living in the area. Although the mosque was designed to promote integration, because it embodies only Turkish elements in its design, it pushes the German population further away as it fails to address the German audience. For the German people living in the area, the mosque remains a foreign building due to the lack of familiar architectural elements. Such a distinct representation is only attractive for the Turkish population living in the area, pushing the German population further away both physically and socially. In addition to this, because the mosque represents a conscious identification with the stereotypical Turkish Muslim identity it disrupts the shared collective imaginaries and self-perception of Germans (Göle, 2011). Seyran Ate , a Turkish born lawyer and women's right activist also warns against the exaggerated expectations regarding the integration-promoting effect of the mosque in Duisburg. She takes a critical position towards the promotion of intercultural and interfaith dialogue and she argues that such dialogue cannot be attained by meeting once or twice a year, during religious festivals. Parallel to Batuman's argument on self-Orientalism, she expresses her fear that such a community center would function as a socialization center among Turkish people, thereby contributing to the consolidation of a parallel Turkish society and provide no social and cultural exchange with Germans.

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Building Fire Risk Assessment Methods: A hierarchical classification

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Abstract

Fire risk is a key element in architecture: sometimes it derives from human action at the time of construction, sometimes from factors over which man has no control. Prevention is frequently the most effective measure to afford it, even when it is known that zero risk is not an achievable goal and we can only reduce it to acceptable levels. One of the prevention tools that architects and engineers can use are the Fire Risk Assessment (FRA) methods. Over the last years, many techniques or approaches of FRA have been developed, and it is possible that the excessive information makes the analyst´s task difficult. This research tries to be a simple and useful review of the main Risk Assessment Methods, ranking them according to their complexity, which will allow the architect or engineer to select the best technique depending on the specific building needs.

Keywords

Fire Risk Assessment Methods; building fire risk analysis; simplified methods; complex qualitative methods, complex quantitative methods.

Building Fire Risk Assessment Methods: A hierarchical Classification

María Fernández-Vigil Iglesias

1. Introduction

Risk prevention is our best tool in order to minimize the consequences that accidents can produce in buildings, even more in case of fire, which involves some unpredictable factors, such as human behavior or the intervention time of the rescue services. That prevention becomes an obligation when there is a possibility of human lives loss.

Recent events, as the Grenfell Tower fire in London last June, demonstrate the importance of prevention. In addition to avoiding the initiation of a fire, it is essential to have an action plan in the case it occurs: how the development of the fire will be, its interior and exterior spread, its detection, the evacuation of occupants and the fire department operation. The failure of these elements has catastrophic consequences: 71 fatal victims in Grenfell Tower.

FRA Methods are a good prevention tool for architects and engineers, in order to evaluate the risk of fire, its possible consequences and the safety measures needed. This paper is a review of the most used methods, and a classification of them according to their complexity. It is a task for the analyst to decide what method is the appropriate in each situation.

2. Definitions and existing classifications

The first problem we face when considering FRA is the different terminology used for each of the phases involved in the process. The terms vary depending on the bibliography consulted, the method selected or even the language used. For example, Assessment and Evaluation do not have the same meaning in English, but they are translated by the same word in many languages such as Spanish: "Evaluación".

Therefore, this study begins with the definition of each of the localized terms, from the most global; "Risk Management"; to the most specific. Risk Management is a concept that involves risk assessment and risk treatment, that is, it includes the elaboration of corrective measures against hazards, in addition to the knowledge of their magnitude.

The SFPE (Society of Fire Protection Engineers) Handbook defines Risk Assessment as "the process of establishing information regarding acceptable levels of a risk and/or levels of risk for an individual, group, society or environment". In this study, Risk Assessment is considered to be composed by two stages: Risk Analysis and Risk Evaluation.

Risk Analysis is the process of identification of the possible hazards, and the estimation of the consequences and probabilities of the adverse effects that could arise from them. Results are presented in a qualitative, quantitative or mixed way. Risk Evaluation consists in making decisions about the level of acceptable risk, based on the results obtained.

Risk Treatment is the process of improving the existing fire safety measures or adopting new ones, that is, the implementation of the assessment result.

Once the terminology is established, the same difficulty is found in the classifications of the different used methods: they differ depending on the consulted bibliography. NFPA 551 divides the methods into: qualitative, semi-quantitative likelihood, semi-quantitative consequences, quantitative and cost-benefit.

John Watts, in the SFPE Handbook, divides the FRA Methods into four categories according to their form: checklists, narratives, indexing and probabilistic methods.

There are many other authors who propose classifications, such as Frantzich, who also makes a distinction between qualitative and quantitative methods, or Fraser-Mitchell, who establishes three categories: Point-Schemes, State Transition Models and Simulation Models. The Spanish engineer J.C. Rubio Romero divides FRA Methods into two large subgroups: Simplified methods and Complex methods, which are subdivided into qualitative and quantitative.

Therefore, according to the different references, FRA Methods can be classified into multiple ways, depending on the chosen criteria. These classification are not mutually exclusive, but they form a complex network, in which the same method may belong to several categories according to the selected criterion. Some of the possible classifications are:

CRITERION	Scenario	Data source	Methodology	Complexity	Factor Analyzed
CATEGORIES	Single scenario	Qualitative	Checklists	Simplified	Consequence
		Semi-quantitative	Narratives		
	Multiscenario		Indexing	Complex	Hazard
		Quantitative	Probabilistic		

Table 1.
Different classifications for FRA Methods.

Not all methods can be classified into one of the above categories, and all categories are interrelated. In addition, sometimes the name of the category is a method itself (as in the case of checklists or indexing).

Some of the methods will be explained and classified below, with the complexity criterion based on the categories used by J.C. Rubio. The following schemes include the most common FRA Methods at international level, and some methods with a widespread use in Spain. Some of them are briefly described, but those specific methods for industrial buildings have not been deeply developed, due to the difficulty on its application.

3. Simplified Fire Risk Assessment Methods
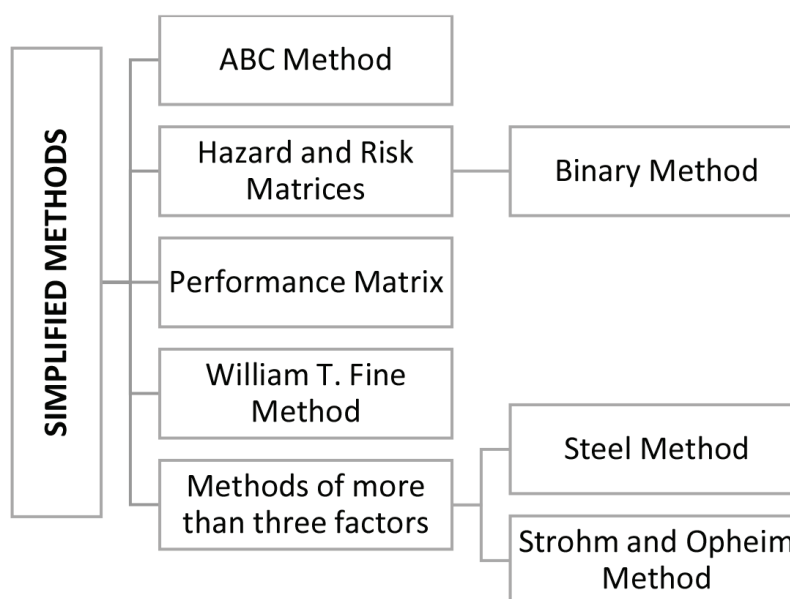
Scheme 1.
Simplified Fire Risk Assessment Methods classification.

3.1. Hazard and risk matrices

The hazard and risk matrices quantify the consequence of possible events for each type of loss (human lives, property, environmental damage…) along one dimension of the matrix, and relative likelihood or frequency along the other. Then, an approximate risk estimate is obtained. In the case of performance matrices, performance groups (building typologies grouped by their use expectation) are compared with the magnitude of designed events.

Each hazard is located in one of three levels, from the lowest to the highest frequency. These hazards are ranked in a second estimate according to the expected negative impact on people, property and environment, and then they are placed in one of three severity levels. Finally, by a comparative matrix, the arithmetic product of probability multiplied by severity is obtained, and the level of risk is determined.

RISK		Consequences		
		Low	Medium	High
Probability	Low	Negligible	Tolerable	Moderate
	Medium	Tolerable	Moderate	Severe
	High	Moderate	Severe	Intolerable

Figure 1.
Example of a Risk Matrix.

	Probability	Consequences	Risk (PxC)
Human Lives	Medium	High	Severe
Property	Medium	Medium	Moderate
Environmental Damages	Medium	Low	Tolerable

Figure 2.
Example of a Risk Matrix applied to a Residential Building.

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3.2. William T. Fine Method

The William T. Fine Method, developed in 1971, decomposes frequency or "probability of occurrence" into two factors: the Exposure or frequency of the initiating events, and the Probability that the accident occurring, once the risk event has been started.

$$Exposure = Risk\ events\ /\ Time$$

$$Probability = Expected\ accidents\ /\ Risk\ events$$

Cost and effectiveness of Fire Protection Measures can be estimated as of these factors, through the following equation:

$$Consequences = Expected\ damage\ /\ Expected\ accidents$$

Therefore, the risk magnitude can be calculated by combining the above equations:

$$Risk = Expected\ damage\ /\ Time$$

$$Risk = C * E * P = (Expected\ damage\ /\ Expected\ accident) * (Risk\ events\ /\ Time) *$$
$$(Expected\ accidents\ /\ Risk\ events)$$

These equations are completed with numerical values, which are available in different sources and tables. Finally, a numerical result will be obtained in order to estimate the severity of the possible hazards.

The collection of all risk situations, ranked according to the severity of their hazards, provides the elaboration of a priorities list, starting with the higher risk. Another aspect added by the Fine Method to the Risk Assessment is the introduction of a factor that determines if the proposed protection actions are justified, according to their cost and effectiveness.

FACTOR	SELECTED CATEGORY / FORMULA	VALUE
Exposure	Rarely (the risk does not occur frequently)	0,5
Probability	If the fire occurs it is possible the catastrophic consequences	3
Consequences	Disastrous (Several deaths)	40
Risk	$Risk = C * E * P$ If risk is between 20 and 70, the risk is possible: it should be corrected, but it is not urgent	60

Figure 3.
Example of the Fine Method applied to a Residential Building.

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4. Complex qualitative methods

COMPLEX QUALITATIVE METHODS

- Historical Analysis
- Preliminary Risk Analysis
- What-if Analysis
- Checklists
  - Safety Reviews
    - Material Safety Data Sheet (MSDs)
- HazOp Analysis (Hazard and Operability)
- Failure Modes and Effect Analysis (FMEA)
- Failures Modes and Effect and Criticality Analysis (FMECA)
- UCSIP Method
- Fire Risk Indexing
  - Insurance Rating
  - Specific Commercial Property Evaluation Schedule
  - Gretener Method
    - Analytic Hierachic Process (AHP)
  - Hierachical Approach
    - Historic Fire Risk Index
  - Dow´s Fire and Explosion Index
    - FireSEPC
  - Mond Fire, Explosion and Toxicity Index
  - MEREDICTE
    - Evaluation system for Business occupancies (EFSES)
  - Fire Safety Evaluation System (FSES)
    - BOCA National Building Code: Section 3408
  - MESERI
    - Building Evacuation Method
  - Software
    - ALARM 1.0
    - ALARM 2.0
    - COFRA
    - EFSES
    - RiskPro
    - Dow Indices
    - FREM
- Dungan Method
- Mosar Method
- Delphi Method
- ITM (Inspection, testing and Maintenance)
- K Coefficient Method
- Alpha factors Methos
- Edwin E. Smith Method
- G.A. Herpol Method
- E.R.I.C. Method
- Estimation of maximum lisses Method
- Intrinsic Risk Method
- Gustav-Prut Method

Scheme 2.
Complex qualitative methods classification.

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4.1. Historical analysis

The historical analysis should be integrated in any Fire Risk Assessment. This technique consists in the research about all the accidents recorded in similar buildings or industries. The analysis reliability depends on the size of the available sample.

As the hypotheses are based on real cases, sometimes the extrapolation of data in not possible, if the fire safety facilities are different than those of the studied building, or if there has not been collected enough information. This analysis is useful in order to make a first approximation to the frequency of occurrence of accidents, and to the possible hazards.

4.2. What-if analysis

The what-if analysis is a "Risk Identification" method, based on a conceptual thinking process. It is a preliminary analysis, which consists in the *"What-if…?"* Question concerning potential undesirable events or scenarios that could happen. It is normally used informally, as a basis for more detailed analysis, and it should be performed by specialists (two or three). The possible triggers of risk situations may be identified from detailed information about the building (and if it is an industrial plant, the materials involved), as well as their consequences and their possible solutions.

What-if analysis can be applied at any stage of the building life; from design, construction and operation until later modifications or even when it ceases its functioning. It is a qualitative method.

4.3. Check lists

Checklists are often used as a quick method for verifying if a building meets the standards requirements. They can be as simple or as complex as the analyst may need, and they can be applied at any stage of the project. This analysis should be performed only by expert personnel, and it shall be based on knowledge of the regulations and codes.

Although the open-ended questions are preferable in order to be valued, checklists usually require a "yes" or "no" response, which does not evaluate the risk, but only identifies it in order to give recommendations.

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FIRE SAFETY CHECKLIST		
IN GENERAL	**YES**	**NO**
Fire extinguishers are present and charged		
Smoke detectors are installed and working		
Carbon monoxide detectors are installed and working		
Fire alarms and exit signs are visible		
There are two exits from any room.		
All cables, plugs etc, are damage-free		
EXITS AND EXTERIORS	**YES**	**NO**
All means of escape are clear and available		
The building exterior and adjacent properties are clean and well maintained		
All doors, stairs and fire escapes are unobstructed and in good condition		
There are at least two ways out from any level or floor of the building		
The building address is visible and clearly marked		
Outdoor areas are free of flammable debris and furniture designed for interior use		
Flammable liquids are not stored in building		
Exit signs and emergency lights are in place and working properly		
LIVING ROOM AND COMMON AREAS	**YES**	**NO**
All furniture, linens, and draperies are made of fire-resistant material		
All interior walls and ceilings are in good condition		
All exit doors are unobstructed and providing sufficient means of egress		
Electric outlets on each wall have covers and are in good condition		
All wall electrical switches work easily and light fixtures work properly		
Hallways and common areas are illuminated		
Windows operate easily and without bars or barriers		
Exit doors free of locking devices that may interfere with exiting		
Dryers, chimneys, wood stoves and all home heating systems are professionally inspected and cleaned annually		
Smoke detectors are in each hallway leading to bedrooms		
KITCHEN	**YES**	**NO**
Electric outlets on each wall have covers and are in good condition		
All wall electrical switches work easily and light fixtures work properly		
Appliances provided appear to be clean and in good working condition		
Appliance electrical cords are in good condition		
Kitchen exhaust and kitchen surfaces are free of grease		
Hot and cold water turns on and off without leaks		
Windows operate easily, exit route is clear, doors work freely		
BEDROOM	**YES**	**NO**
Mattress, furniture, linens, and drapery is made of fire-resistant material		
Interior walls, ceiling and floor are in good condition		
Outlets have covers and are in good condition		
All wall electrical switches work easily and light fixtures work properly		
Smoke detector is present near bedroom and operating		
At least one window operates easily and is not obstructed by bars		
Door works freely, latches and locks are functional		

Figure 4.
Example of a checklist for the fire safety evaluation of a residential building.

4.4. Fire risk indexing

Fire Risk Indexing is an assessment method for fire safety. On the one hand, it consists in the analysis and assessment of the building hazards, in order to produce a simple result that estimates the relative risk of fire. On the other hand, values are assigned to positive and negative safety measures. Then, the analyst operates with arithmetic functions until a simple value, which is compared to other evaluations. It is a simple, effective, semi-quantitative method. It may be appropriate in several situations: When a high level of sophistication is not required, when the analysis is required to be economically effective, and when there is a need to communicate the level of risk. This type of methodology is also known as rating schedules, point schemes, ranking, numerical grading and scoring. There are several indexing techniques. Some of them have been developed for the evaluation of industrial buildings; there are indices for specific national regulations (i.e. MEREDICTE and MESERI in Spain); there are international indices…

The Gretener Method is widely used in Europe. It is a risk index developed between 1960 and 1965 by the Swiss engineer Max Gretener. The process consists in numerically expressing the factors for fire initiation, and the factors of protection: fire risk is measured as the ratio of negative features that increase risk and positive features that decrease risk. A Potential Fire Risk is calculated and compared to an Admissible Potential Risk. It is a very complete method in terms of the number of factors it evaluates, but it should be performed by an experienced operator.

The calculation is based on:

$$R = B * A = (P / M) * A$$

Where:

B = Fire Hazard (P/M)
A = Probability of ignition. This factor is left open to the subjectivity of the analyst.
P = Potential hazard
M = Protection measures.

"P" is composed by the product of all dangerous factors, both content (fuel load density, combustibility, smoke formation, corrosion or toxicity) and continent (fuel load density, height or floor level and amplitude of fire compartments). Therefore, it evaluates the intrinsic risk conditions for the developed activity and the construction characteristics of the building.

"M" is the product of all protection factors: normal measures (portable fire extinguishers, hydrants and hose...), special measures (detection and alarm systems, fire intervention, automatic extinguisher systems and smoke control...) and fire resistance of the building (structural elements, facades, firewall cells...).

Once the value of the Effective Fire Risk (R) is calculated, an Accepted Fire Risk (Ru) value is set; such value is obtained from a Normal Risk value (Rn = 1.3), which is corrected by a factor that takes into account the danger to people (PHE). This factor is calculated with the capacity of the floor, its height with respect to the level of the ground and the people exposure to the risk, (which is determined by the ease or difficulty of evacuation).

$$Ru = Rn * P_{HE}$$

From the comparison between Effective Fire Risk and Accepted Fire Risk, we can deduce whether or not fire safety is sufficient. For this purpose, the Fire Safety Factor (γ) is used:

$$\gamma = Ru / R$$

If γ <1, the fire safety of the building or compartment is insufficient and corrective measures must be taken.

In summary, Gretener Method is a specific FRA Method, which is very useful for the evaluation of fire risk in high-occupancy buildings or those with specific evacuation problems (hospitals, hotels, etc.)

This index is the most used and there are a lot of variations of it, in order to create specific index according to the different national regulations. For example, in the Spanish Building Code there is an official document for the evaluation of the fire risk in non-industrial buildings, by the use of an index. The method is called MEREDICTE, and it is based on the Gretener Method for its application in Spanish buildings.

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// **Building Fire Risk Assessment Methods:**
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FACTOR	DEFINITION	SELECTED CATEGORY / FORMULA	VALUE
NRG	Global Risk	$NRG = \dfrac{PP}{NPG}$	0,67
NRE	Building Risk	$NRE = \dfrac{PP}{NPE}$	0,67
PP	Potential Hazards	$PP = AS * (0,4 * T + 0,3 * CO + 0,3 * CA)$	1,90
AS	Number of people in the compartment	0 < people < 65	0,80
T	Fire tetrahedron	$T = TC * TCM * TEA * TRC$	2,66
TC	Combustible	$TC = c1 * c2 * c3 * c4 * c5 * c6$	2,02
c1	Content Fuel load density	Housing Residential	1,40
c2	Continent Fuel Load density	Non-combustible facades and structure	1,00
c3	Combustibility	Housing Residential	1,20
c4	Smoke	Housing Residential	1,00
c5	Corrosion and toxicity	Housing Residential	1,00
c6	Fire development	Housing Residential	1,20
TCM	Comburent	Normal Atmosphere	1,00
TEA	Activation Energy	$TEA = ea1 * ea2 * ea3 * ea4 * ea5$	1,10
ea1	Activation Danger Coefficient	Housing Residential	1,00
ea2	Special Hazards	There is a protected Low Risk Local	1,10
ea3	Reparation	There are not reparations	1,00
ea4	Electrical installation	It complies with the regulations	1,00
ea5	Heat systems and Decorative elements	There are not	1,00
TRC	Chain reaction	The fire compartment allows the vertical spread	1,20
CO	Occupants characteristics	$CO = co1*co2*co3*co4*co5*co6*co7$	1,04
co1	Vulnerability	Normal occupants	1,00
co2	Familiarity	The occupants are familiar to the building	0,80
co3	Sleeping occupants	Occupants may be sleeping	1,45
co4	Obstacles	There are not obstacles	1,00
co5	Occupation Load	Low Occupation Load (10-20 m2/person)	0,90
co6	Panic	It is not expected a panic situation	1,00
co7	Orientation	There is no risk of disorientation	1,00
CA	Building Characteristics	$CA = ca1*ca2*ca3*ca4*ca5*ca6*ca7$	3,34
ca1	Fire Compartment Area	1000 m2 < Sc < 1500 m2	1,10
ca2	Evacuation Height	18 < Ev. Height < 28	2,20
ca3	Underground floors	There are not underground floors	1,00
ca4	Ceiling Height	2,78 < h < 3,34	1,15
ca5	Facade accesibility	One accesible facade	1,20
ca6	Facade absorptivity	720 < B < 2500	1,00
ca7	Facade ventilation		1,00

Figure 5.
Example of MEREDICTE Index applied to a residential building (Risk factors).

FACTOR	DEFINITION	SELECTED CATEGORY / FORMULA	VALUE
NPG	Global Protection Level	$NPG = NPA*NPE$	2,85
NPA	Self-Protection Plan	Not required	1,00
NPE	Building Protection level	$NPE = RFE*(0,24*P + 0,4*EO + 0,24*IPCI + 0,12*IB)$	2,85
RFE	Fire Resistance of the Structure	It complies with the regulations	1,15
P	Fire Spread	$P = PI*PE$	1,26
PI	Interior Spread	$PI = PI1*PI2$	1,20
PI1	Fire Compartments	$PI1 = pi1.1*pi1.2*pi1.3*pi1.4*pi1.5$	1,20
pi1.1	Fire Resistance of floors and ceilings	EI 90	1,00
pi1.2	Fire Resistance of doors	Half Resistance of ceilings and walls	1,00
pi1.3	Compartmentalization of elevators	There are not elevators between sectors	1,00
pi1.4	Doors between compartments	It complies with the regulations	1,00
pi1.5	Pass of systems	They are compartmentalized	1,20
PI2	Fire Reaction	$PI2 = pi2.1*pi2.2*pi2.3$	1,00
pi2.1	Reaction to fire of construction elements	It complies with the regulations	1,00
pi2.2	Reaction to fire of textile elements	There are not textile elements	1,00
pi2.3	Reaction to fire of decorative elements	There are not decorative elements	1,00
PE	Exterior Spread	$PE = pe1*pe2$	1,05
pe1	Fire Spread: Facades and Roofs	It complies with the regulations	1,00
pe2	Reaction to fire of facades and roofs	It complies with the regulations	1,05
EO	Evacuation of Occupants	$EO = EO1*EO2*EO3*EO4*EO5*EO6*EO7*EO8$	4,72
EO1	Number of exits	Only one exit is required	0,90
EO2	Evacuation routes Lenght	There is one exit, and the distance is less than 15 meters	1,60
EO3	Dimensioning of the means ef egress	It complies with the regulations	1,00
EO4	Evacuation Routes Protection	$EO4 = eo4.1*eo4.2*eo4.3*eo4.4*eo4.5$	2,40
eo4.1	Type of Evacuation	Vertical egress	1,00
eo4.2	Type of horizontal Egress	Vertical egress	1,00
eo4.3	Type of vertical Egress	Protected stair	2,00
eo4.4	Stairs Continuity	The stair lead to a minimum risk compartment	1,20
eo4.5	Stairs ventilation	Passive systems (windows)	1,00
EO5	Doors in evacuation routes	$EO5 = eo5.1*eo5.2*eo5.3*eo5.4$	1,05
eo5.1	Opening direction of the door	Doors open in the evacuation direction, if they will be used for more than 100 people	1,00
eo5.2	Opening System of the doors	It complies with the regulations	1,00
eo5.3	Type of doors	Vertical rotation axis	1,05
eo 5.4	Automatic doors	There are not	1,00
EO6	Signaling of the means of egress	It complies with the regulations	1,00
EO7	Smoke Control	It is not required	1,00
EO8	Disabled People Evacuation	There are refuge areas in the protected stairs	1,30
IPCI	Fire Safety Systems	$IPCI = IPCI1*IPCI2*IPCI3*IPCI4$	0,63
IPCI1	Detection and Alarm	$IPCI1 = ipci1.1*ipci1.2*ipci1.3*ipci1.4*ipci1.5*ipci1.6$	0,70
ipci1.1	Detection system	There is not detection system	0,70
ipci 1.2	Types of detectors	There is not detection system	1,00
ipci1.3	Detectors Identification	There is not detection system	1,00
ipci 1.4	Alarm System	There is not detection system	1,00
ipci 1.5	Detection Central	There is not detection system	1,00
ipci 1.6	Alarm Communication to the Fire Department	There is not detection system	1,00
IPCI 2	Extinción manual	$IPCI2 = ipci2.1*ipci2.2*ipci2.3*ipci2.4$	0,90
ipci 2.1	Extinguishers	There are extinguishers	1,00
ipci 2.2	Dry Column	There is not Dry Column	1,00
ipci 2.3	Hydrants	There is not Hydrant	1,00
ipci 2.4	Hoses	There are not hoses	0,90
IPCI 3	Suppression System	$IPCI3 = ipci3.1*ipci3.2$	1,00
ipci 3.1	Suppression System Disponibility	There is not Suppression System	1,00
ipci 3.2	Suppression System Objective	There is not Suppression System	1,00
IPCI4	Complementary security systems	$IPCI4 = ipci4.1*ipci4.2*ipci4.3$	1,00
ipci 4.1	Means of escape Signage	Yes	1,00
ipci 4.2	Emergency elevator	No	1,00
ipci 4.3	Emergency Lighting	Yes	1,00
IB	Fire Department Operation	$IB = ib1*ib2*ib3$	1,12
ib 1	Accesibility for firefighters	4 fachadas accesibles	1,40
ib 2	Distance from the fire department	10 km < d < 25 km	0,80
ib 3	Private Firegithers	No	1,00

Figure 6.
Example of MEREDICTE Index applied to a residential building (Protection factors).

4.5. Maximum Loss Estimation Method

The Maximum Loss Estimation Method (or PML-EML) is a semi-quantitative quantification of fire risk, by estimating the economic losses under three possible scenarios: the most pessimistic, the most probable and the most optimistic. For each scenario the assets are valued and the economic loss is calculated. This model is widely used by insurance companies, as their approach is strictly economic. It is used for the evaluation of hypothetical fire situations, although it could be applied in more scenarios predicting all types of economic losses.

4.6. Gustav-Purt Method

The main aim of the Gustav-Purt Method is to objectively determine what type of risks requires the installation of special security measures. The Purt Method assumes that the destructive action of fire takes place in two distinct areas: the building and its contents. Therefore, two independent coefficients, for the building and for the content, are calculated.

The risk of the building (GR) lies in its possibility of the destruction, depending on two factors:

- The intensity and duration of the fire.

- The resistance of the construction.

GR depends on: the fuel load of the contents and of the building, the combustibility of the materials, the area and situation of the fire compartment, the time lapsed until the intervention begins, the fire resistance of the structure and a reduction coefficient to be applied in some cases.

The risk of the content (IR) is constituted by:

- Harm to people

- Damage to the material assets inside the building.

For GR calculation, it is important not to exceed a specific limit value, but in the case of IR it is stricter, since it refers to people or goods of value. This double meaning is taken into account in a graph (the Measurement Diagram). GR is represented in ordinates (in the example, 1.41), and IR is represented in abscissa (in the example 3.0), so that each combination of both values corresponds to a point in a two-dimensional plane. The position in this plane allows the determination of an overall risk level and an assessment based on it, translated to a level of requirements of the fire safety measures: : in this case, we are in the region "3", so the recommended measures is the installation of a detection and alarm system. A first orientation on the appropriateness of the preventive measures is then obtained, but it should be later examined in more detail.

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FACTOR	DEFINITION	SELECTED CATEGORY / FORMULA	VALUE
GR	Risk of the building	$GR = \dfrac{(Qm * C + Qi) * B * L}{W * Ri}$	1,41
Qm	Fuel load of the contents	481-960 Mcal/m2	2,0
C	Comustibility	Medium	1,2
Qi	Fuel load of the building	0-0,80 Mcal/m2 (concrete and bricks)	0,0
B	Fire Compartment Area	Less than 1500 m2	1,0
L	Time until the invtervention begins	Fire department distance: 12 km	1,5
W	Fire resistance of the structure	F-90	1,6
Ri	Reduction coefficient	There are not combustible materials storage	1,6
IR	Risk of the content	$GR = H * D * F$	3,0
H	Harme to people	Tpeople may be impaired or can not evacuate	3,0
D	Damage to the material assets	The assets does not have an important value	1,0
F	Smoke Action	Without a particular danger for smoke or corrosion	1,0

Figure 7.
Example of Purt Method applied to a residential building.
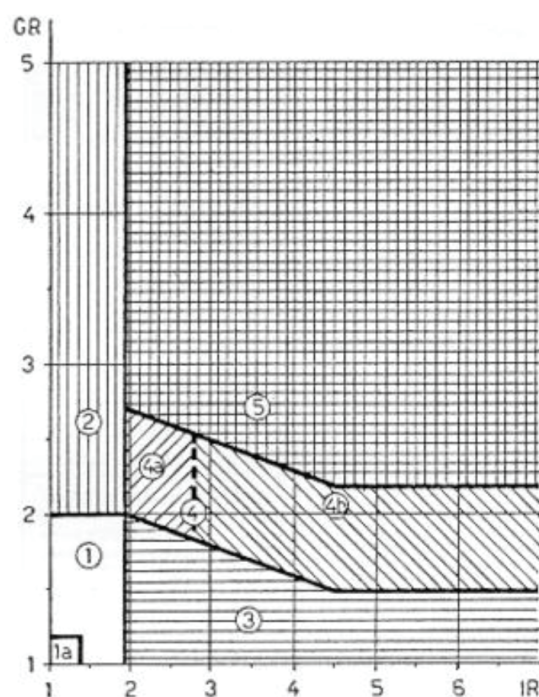
Figure 8.
Measurement diagram of the Gustav-Purt Method.

5. Complex Quantitative Methods

Quantitative methods answer three questions numerically:

-Frequency of events.

- Severity of damage.

- Total resulting risk.

The first question is answered by applying the probabilistic analysis and by calculating the likelihood of occurrence of an undesired event by using reliable baseline data. The second question is answered by applying methods for the calculation of effects and damages. Finally, the third question is solved by multiplying frequency by severity of the accident, and the evaluation of its acceptance or not.

5.1. Fault Tree Analysis

Fault Tree Analysis (FTA) were conceived in 1962 by H.A. Watson. It has been applied in space, nuclear, chemical, petrochemical and electronic industries.

It is a top-down or "reverse" thinking process, that is, a deductive technique that focuses on a particular event that may occur, and provides a framework for assessing the potential causes of that event, instead of starting from the causes and reaching the consequences. For this purpose, a structure is provided in the form of a graphical representation and the analyst uses it for placing the events, conditions, actions and results. FTA is a series of combinations of initial events that could lead to a failure; and may include components, equipment and operational systems, and / or human actions and errors.

Previously, accidents or "top events" must be identified through the use of other methods such as preliminary risk analysis or historical analysis, and their frequency of occurrence must be quantified. From this "Top Event", the intermediate events will be found, as well as the basic events that cannot be further decomposed.
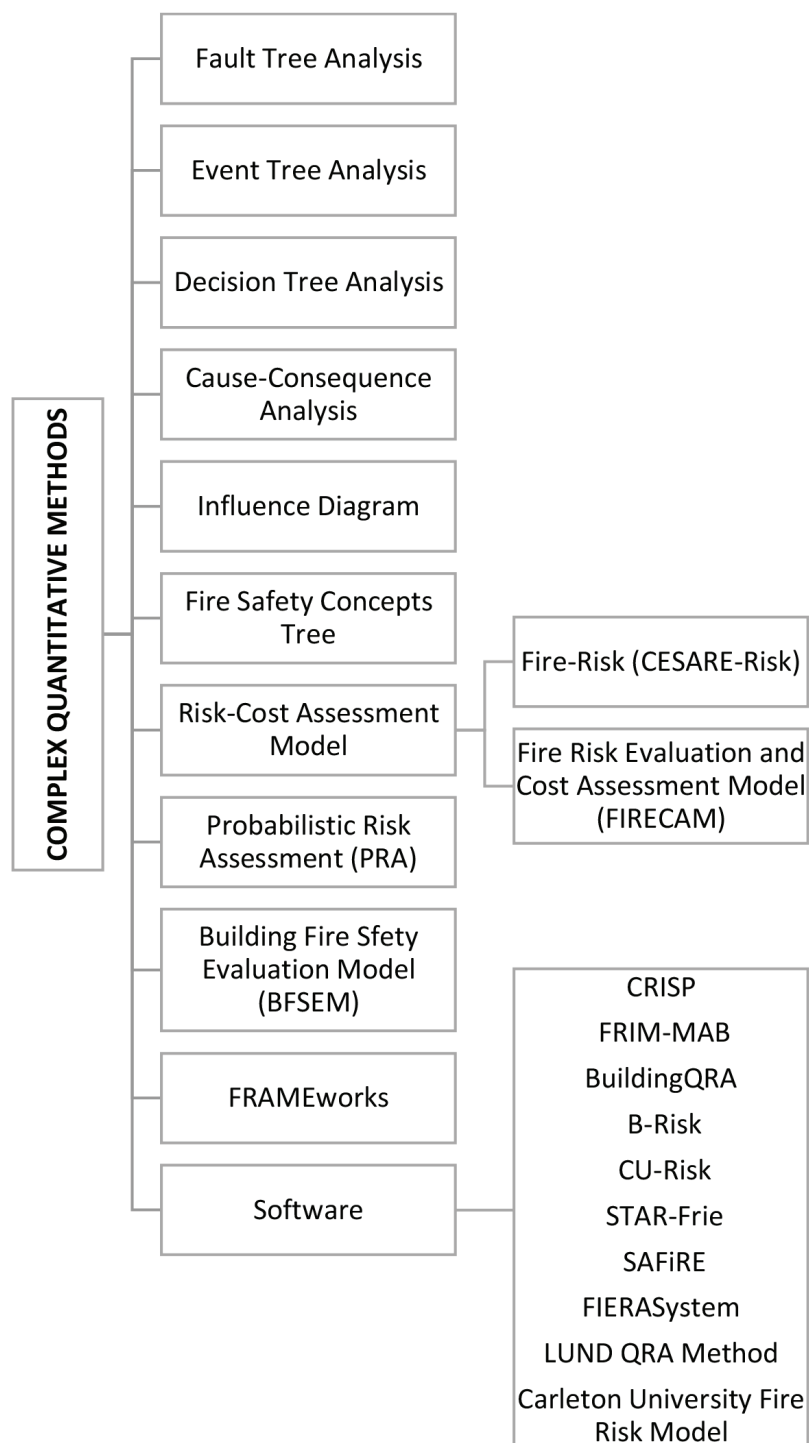
The deductive process of the fault tree is divided into two phases:

-The development of the tree
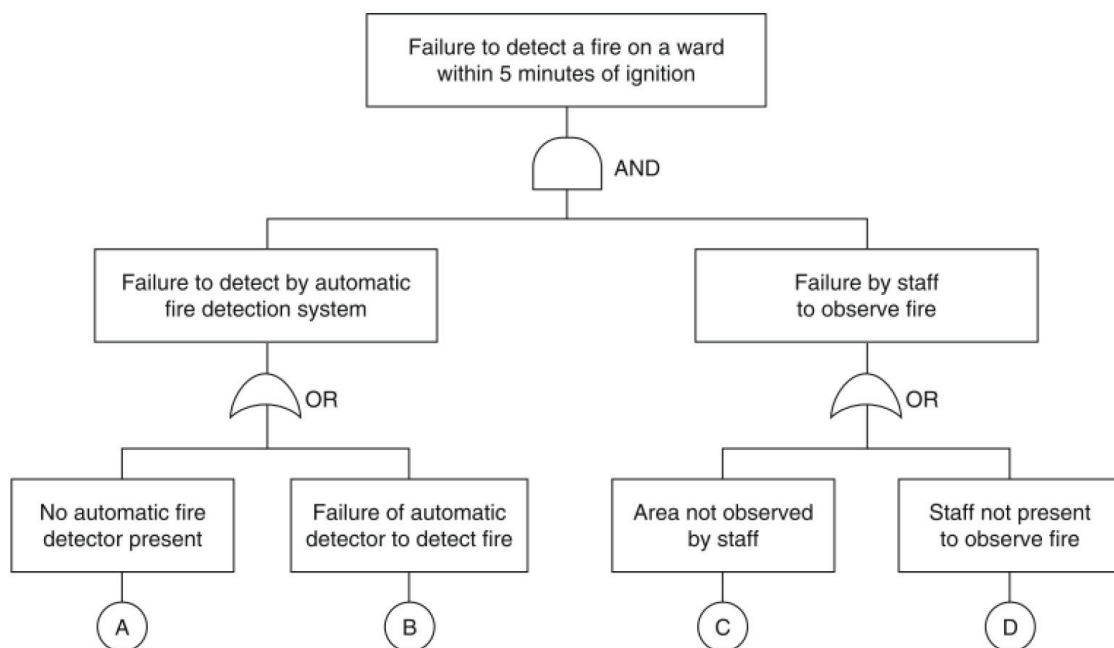
-The quantification of the tree

Although it is initially a qualitative method, if probabilities or frequencies are given, it could be used as a quantitative method. For this purpose, the probabilities or frequencies of the initial events are combined using the "AND" and "OR" gates. The use of the "AND" gate implies that all branches derived from the upper event may occur. In contrast, if the "OR" gate is used, only one of the leads can occur. The branches are mutually exclusive.

Assigning a probability or frequency to each event of the tree, and combining them according to "AND" "OR" rules, the probability or frequency of the initial event can be extracted.

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COMPLEX QUANTITATIVE METHODS

- Fault Tree Analysis
- Event Tree Analysis
- Decision Tree Analysis
- Cause-Consequence Analysis
- Influence Diagram
- Fire Safety Concepts Tree
- Risk-Cost Assessment Model
  - Fire-Risk (CESARE-Risk)
  - Fire Risk Evaluation and Cost Assessment Model (FIRECAM)
- Probabilistic Risk Assessment (PRA)
- Building Fire Sfety Evaluation Model (BFSEM)
- FRAMEworks
- Software
  - CRISP
  - FRIM-MAB
  - BuildingQRA
  - B-Risk
  - CU-Risk
  - STAR-Frie
  - SAFiRE
  - FIERASystem
  - LUND QRA Method
  - Carleton University Fire Risk Model

Scheme 3.
Complex quantitative methods classification.

Figure 9.
Simple fault tree-fire detection in a hospital ward (Meacham 2015).

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Phase 1: Elaboration of the tree: This phase consists in a deductive process, based on Boolean algebra laws. It starts from the undesired event (Top event) for finding out its origins, decomposing it into intermediate events until the basic events are reached (which cannot be further decomposed) or undeveloped (for lack of information). Both types, basic or not developed events, are independent one from the other, and they have associated a probability of occurrence that can be calculated.

Phase 2: Tree Quantification: In this process, the tree will be reduced until the obtainment of the minimum combination of primary events whose simultaneous occurrence would lead to the occurrence of the Top event. Each of these combinations is a "minimum set of faults". Since the basic events are independent one from the other (that is, the occurrence of one has no influence on the occurrence of the other), the probability of a minimum set of faults is given by the product of the probabilities of the elementary events that conform this set. The Top event will be represented by the logical union of all "n" minimum sets of faults and their probabilities, by applying the theorem of total probabilities.

The technique is quite complex, so there are computer programs that help its resolution.

5.2. Event Tree Analysis

Unlike the FTA, which starts from a fault and looks for causes, the Event Tree Analysis (ETA) provides a structure to postulate an initial event, whose frequency of occurrence is known, and it analyzes the possible consequences. The main tool is a decision tree, with branches that imply success and failure (yes / no or other similar binomial). It consists in the identification of an initiation event, of the systems or strategies used to its mitigation, and the question about the success or failure of each system or strategy. This method allows the analyst to find out the different sequences of accidental events that can be triggered, and to know the possible consequences and probabilities of the different accidents that may occur. From this knowledge it is possible to verify that existing and planned preventive measures are sufficient for the limitation or reduction of undesired effects. As with FTA, ETA is in principle a qualitative tool, which becomes quantitative at the moment in which probabilities or frequencies are assigned to each branch. The probabilities of each factor can be estimated by using a combination of historical data and expert judgment, leading to an estimated probability for a possible consequence (scenario). Data can be obtained from fire statistics or other observations and measurements.

Event Tree Analysis are very useful for the analysis of systems whose components have a sequential relationship. The stages that compose it are generally the following:

A. Construction of the event tree. Starting from the top event on the left, two bifurcations are presented on the right, reflecting in the upper part the success or occurrence of the conditioning event and, in the lower part, the failure or non-occurrence of the conditioning event. 2N combinations or theoretical sequences are obtained, although due to the dependence between the events, it can result that the occurrence or success of one of them, may eliminate the possibility of other events.

B. Quantification of the tree. The initiation event has a frequency "f", as well as the "N" conditioning factors or accidental events, each defined by its probability of occurrence, "p". Complementary events will have associated a probability of 1-p occurrence.

After the construction and quantification of the tree, it could be useful to classify the answers into categories of similar consequences, for the subsequent study of the consequences model.
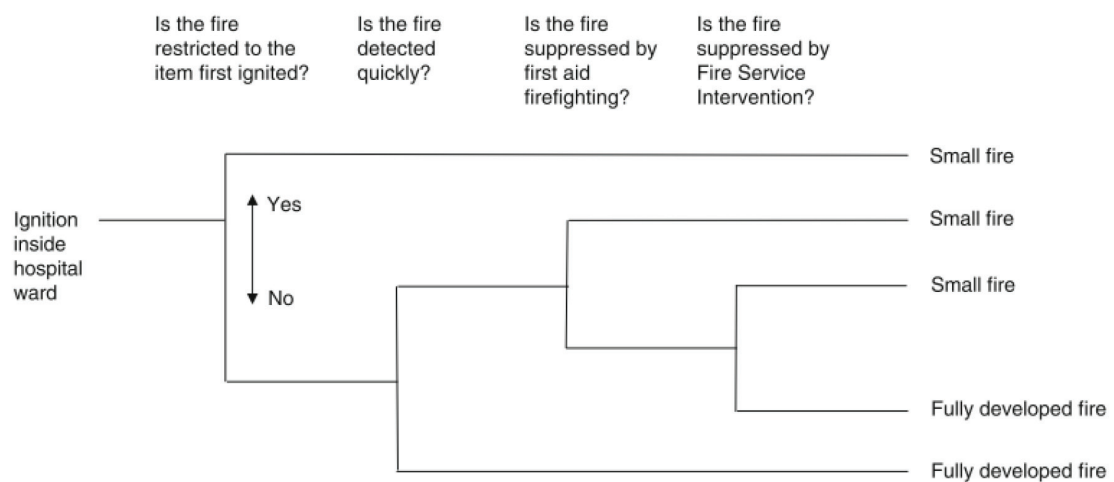
Figure 10.
Simple event tree- fire extinguishment in a hospital ward (Meacham 2015).

Conclusions

Risk Assessment Methods are a very useful tool in order to deal with possible hazards that we can face in a building due to its specific characteristics of use, operation, design… Fire is one of the most dangerous potential hazards, as it involves the design of the building, human behavior and the development of the fire itself. Fire in buildings is very difficult to predict. Therefore, FRA Methods are needed in order to propose effective protection actions. The present study aims to show an overview in the field of Fire Risk Assessments, by making a classification, which is susceptible of being extended, by following the complexity of use criterion. The objective has been to provide the analyst with the necessary tools for selecting the most appropriate method to each specific situation. Such choice is not a minor task, since some methods are too complex to be used with-out previous experience in the matter, and all of them must be used with the knowledge of their limitations.

Acknowledgement

Building Fire Risk Assessment Methods: A hierarchical Classification
María Fernández-Vigil Iglesias

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Antonis Papamanolis was born in Wales, Great Britain in 1983 and holds a Diploma in Architectural Engineering from the University of Patras, Greece. He is a Doctoral Candidate of the Department of Architecture of the University of Patras. The title of his thesis is "Digital Design Media and Architectural Pedagogy – towards a Hermeneutic Approach of Introducing Computational Design in Architectural Education". Has worked in various architectural offices as well as being the CAM Lab Supervisor at the Architectural Department of the University of Patras. Currently is an Adjunct Professor at the Italian Marconi University, as well as working as a freelance architect in Athens, Greece. Has published five papers on issues regarding Design Education, Architectural Pedagogy and CAAD.

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Irem Öz is a Ph.D Student at the Pennsylvania State University, in her paper "The Tale of the Miracle of Duisburg: A Miracle or an Illusion" presents the story of the DITIB (Turkish-Islamic Union for Religious Affairs in Germany) commissioned Maxloher Merkez Mosque in Duisburg, Germany. While investigating three factors that contribute to the successful reception of the mosque by the public: (1) the architecture and urban design process of the mosque (2) local context and (3) the politics of visibility; this research also argues that although the Marxloher Merkez Mosque project is perceived as a successful project that managed to overcome the risks associated with social conflict, this "Miracle" of Duisburg only provides social cohesion on the surface and leads to "self-orientalism" and further alienation.

María Fernández-Vigil Iglesias is a PhD student from the University of Navarre. She studies the Fire Risk in Dwellings occupied by Elderly people in Spain. In her paper she argues that Fire risk is a key element in architecture, because it involves three factors: those related to the building, those related to the people using the building and those related to fire itself. Architects have no control over those factors once the fire has started, so prevention is the best tool we have. The paper "Building Fire Risk Assessment Methods: A Hierarchical Classification" is an important part of the development of her dissertation, while FRA Methods are one of the most effectives measures to prevent fire accidents. This research tries to be a useful review of the main Risk Assessment Methods, ranking them according to their complexity, which will allow the architect or engineer to select the best technique depending on the specific building needs.

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// Next Issue Information

Intelligence

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The 11th issue of the **archiDOCT** e-journal revolves around the notion of intelligence as this has entered the domain of the built environment and its design both in practical and theoretical terms. Intelligence has become a buzz word that accompanies every possible action, praxis, process or product nowadays. A trend that is being arising due to the rapid development of information and communication technologies. Most importantly though, the concept of intelligence triggers research that either questions the primacy of humanity or establishes it further by locating it in diverse cultures or in a closed privileged human-centred culture. The design of the built environment, at any scale incorporates intelligence at its every stage. It veils the ruins of our existing constructions but it also unveils constructions of an alien intelligence. It underlies notions of control, management efficiency in a neo-cybernetician mode, but also notions of sensing, abstracting, learning, deciding and acting in either a human or non-human like manner. It moves constantly between an effective and smart management of presented resources and a spontaneous creation of smart platforms that afford the participation of anything called user that includes human and non-human entities. It is in this vastness that the contribution of new and existing paths is needed in order to encompass intelligence intelligently and to map its implications in design at any possible scale. The range of its theorisation and its application is vast and a cartography is possibly needed. From smart cities to material intelligence, from machine learning algorithms to alien forms of abstraction, design is open to incorporate any possible instance of intelligence both in methodological as well as in practical terms. The 11th issue of **archiDOCT** e-journal welcomes essays that explore the concept of intelligence in theoretical and practical terms, in human and non-human actualisations of it. It is a call that scans the emergent field of research and design that spans from *intelligent buildings to building intelligences.*

This **archiDOCT** issue invites doctoral research essays focusing on any field related to architecture where intelligence is mobilised at any scale and stage of its theorisation and actualisation. Authors are encouraged to construct arguments for or against any idea of intelligence in general and in design in particular. This emergent field requires a provisional cognitive mapping that this issue is hoping to construct.

Important dates:

Submission deadline (full papers): 15 March 2018
Review period: 16 March 2018 - 15 April 2018
Revision period: 16 April 2018 - 30 April 2018
Follow-up review: 01 May - 15 May 2018
Final revision: 16 May - 31 May 2018
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Submission Policy

archiDOCT is published two times a year, in February and July. The official language of the journal is English. Submitted manuscripts for review should not exceed 4500 words, including abstracts, references and image captions. The referring system will be the Harvard System. Text should be saved in a Microsoft Word or RTF file, while the supporting visual material (images, diagrams, sketches, tables and so on) should be sent as TIFF files with a resolution of at least 300 dpi. All visual material should be clearly indicated and numbered in the text, along with the respective image captions and credits. Additionally, all manuscripts should be submitted in A4 "camera-ready" PDF format that gives an idea of how a finalized version looks like.

archiDOCT only accepts manuscripts from PhD students. In order for an article submission to be considered for publication, the student must be a registered and active member of the ENHSA Observatory (www.enhsa.net/main/observatory), a PhD research portal created to facilitate communication and meaningful information exchange between architecture doctoral students.

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The peer reviewers are all confirmed educators of architecture coming from different educational backgrounds, with different specialisations and expertise that share the common interest of their doctoral students: to encourage them to publish their work while improving their thinking processes towards academic research writings. Each submitted article is reviewed by two members of the journal's Scientific Committee anonymously.

Copyright policy

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