

INTEGRATED PROJECT DESIGN IN CIVIL ENGINEERING MASTER OPORTO UNIVERSITY

Rangel, B¹

Secção de Construções Civas – DEC

FEUP

brangel@fe.up.pt

Brandão Alves, F

Secção de Construções Civas – DEC

FEUP

alves@fe.up.pt

Conference Topic: Engineering Design

1 INTRODUCTION

These days, a building is required to be as efficient as any domestic appliance, but there is probably not a single machine produced by Man that involves so many systems and so many people. The performance efficiency demanded of buildings in service by the different stresses to which they are subjected has been imposing in recent decades an increasing rigour in the definition of the various projects, particularly in the degree of scientific and technical depth in the solution presented. To reduce the construction time and anticipate this building performance, greater specifications are expected from the various disciplines involved in the design for the constructive solutions they propose for each subsystem. It is the perfect articulation of all these subsystems - structural, hydraulic, acoustic, electrical, etc. that will establish the perfect functioning of the building as an INTEGRATED SYSTEM. Architecture, thermal insulation, acoustics, structures and hydraulics inevitably come together to design the solution, because the same building elements often belong to different subsystems. The same wall might be the structural support for a slab, an acoustic barrier in a room or a thermal barrier to the outside.

From the initial sketches to the specifications of the various materials, the design cannot definitely be a sequence of responses, but the result of a complex algorithm of the different responses of the various disciplines, the INTEGRATED DESIGN. The resolution of this algorithm, the DESIGN OF THE CONSTRUCTION, lies in the common ground that underlies all the disciplines. In determining the dimensions, the materials and the construction solutions, each member of the team must identify the solution that meets the requirements of his or her discipline. The optimal solution corresponds to the weighting of the responses from each of them. In designing a room of 200m², for example, the architect cannot design the openings to the outside without knowing what the ideal relationship is between natural and artificial lighting. He cannot define the shape without the acoustician determining the ideal volume for the interior space or design the finishing materials without knowing the desired degree of reverberation. Much less scale the form without knowing the dimensions of the horizontal and vertical structural components needed to achieve a

span of 15 or 20m. The final solution for the form, the spans, the constitution of the envelope are therefore the result of the articulation of all these decisions. It is an algorithm that unites the optimal values of each discipline to find the suitable dimensions of the various components of the architectural form.

Since all the disciplines are seeking the same answers to the same equation, the same dimensions, materials and construction solutions, it is essential that, from the beginning of their training, they understand the importance of the decisions of others to substantiate their own solutions. To be able to understand this multidisciplinary approach, they must all master/establish a common language: building. For future architects, how the mathematical language of engineering translates into compositional elements of the construction. For future engineers how construction translates into architectural language.

Before they learn to deal with the numerous computer programs that can articulate the different projects (BIM), both must first of all be shown that colour, lighting, natural ventilation, spatial organisation are measurable and assessable, to be worked in an integrated way with the goal of creating a single body, the INTEGRATED SYSTEM.

2 THE INTEGRATED PROJECT AS INTUITION

Not so many years ago, construction work was a laboratory of ideas that were studied in the office and fine-tuned with the craftsmen who would put them into practice. Architects and engineers learned to discover the secrets of construction during periods of work experience. They made contact with other disciplines, paid visits to construction sites and learned from the experience of their seniors. In designing a window frame, they would consult the thermal engineer, but also seek the approval of the carpenter, the contractor and the glazier. Construction was learned on the job.

However, this knowledge of CONSTRUCTION that was acquired over time, by getting their hands dirty, is no longer possible. In building works, “miraculous” solutions are sought to find ways of reducing the investment and the time required for building. The behaviour of the building needs to be more effective in responding to demands for comfort. The project has to be done quickly. The work has to be carried out within the lowest budget and finished in record time, but the performance has to be the best... and the designers are always held responsible for any failure.

This methodological complicity is practised in the best architecture and engineering offices. Integrated design is now already being practised in some of the best offices in Portugal and abroad. In some, these principles have arisen almost intuitively, in others the management of the office is based on an interdisciplinary approach.

Eduardo Souto de Moura admits that he does not draw the first line of a design without having at his side the structural engineer, Rui Furtado, who has been working with him:

“It's all done in a constant dialogue and everything is constantly evaluated”

(Abrantes et al. 2009)

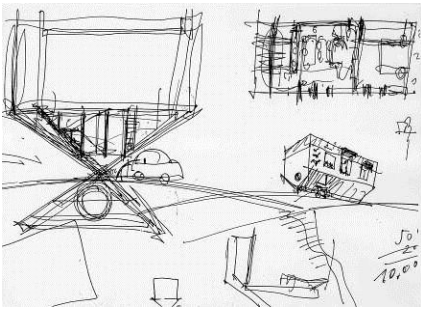


Fig. 1 Eduardo Souto Moura's sketch for a house in the Douro (Abrantes et al. 2009)

Álvaro Siza says that he is advised from the outset by a number of structural engineers, mechanical engineers, etc. on the needs that each discipline will have in the building, aiming at the early physical integration of all the subsystems:

"I have the time to think globally, because I have good engineers."

(Abrantes et al. 2010)

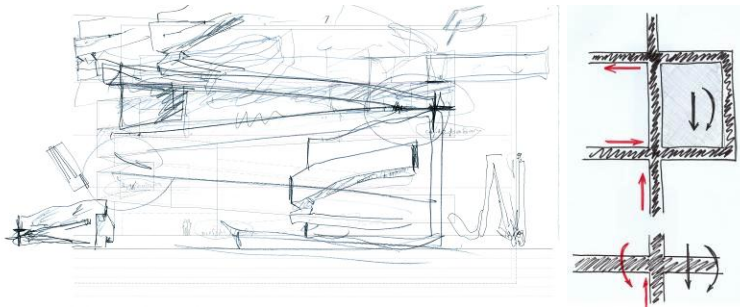


Fig. 2 Sketch by Álvaro Siza of the Iberê Camargo Foundation in Brazil (Abrantes et al. 2010)

Fig. 3 Sketch by Engineer Jorge Silva of the Iberê Camargo Foundation in Brazil (Abrantes et al. 2010)

In a building as complicated as the laboratory research centre of the Faculty of Sciences at Columbia University, Rafael Moneo uses as a score for the composition of the façade the algorithm of structural composition of a façade suspended over a large span:

"In its final form, the structural bracing emerges as a kind of texture mounted on the prism, leading us to think that the façade of the building is an intentional composition inspired by the work of Paul Klee, when in reality it is the result of rigorous structural analyses: more a product of deductive reasoning than an artistic gesture."

(Abrantes et al. 2011)

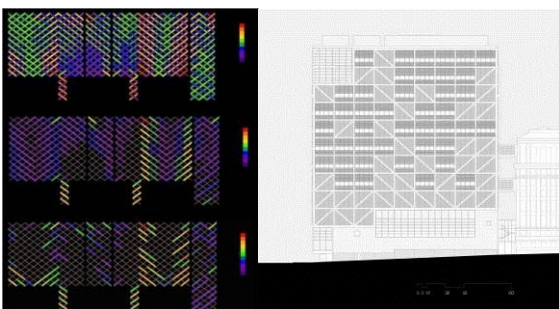


Fig. 4 Numerical simulation of the façade by Ove Arup, NY, Faculty of Science, Columbia University, New York (ARUP 2009)

Fig. 5 Main Architecture elevation by Rafael Moneo (Abrantes et al. 2011)

This integration is almost intuitive, arising as the need for an effective response to the projects. Greater demands, faster responses and greater responsibility have obliged these architects to engage a good team to complement this response. They all recognise that, although the act of architectural design begins as an intuitive response to a given brief, the participation of the whole team is essential from the early stages. Moreover, the demands imposed on the effectiveness of the design for the optimal performance of the building require greater accountability from the entire team, making its perfect organisation inevitable if a truly integrated project is to be achieved. However, the efficacy of this teamwork is not easy to achieve; it so often implies that a special orchestrated harmony must be found in the strong friendship ties that gradually give rise to a particular methodology, achieved with a lot of personal and professional experience.

3 THE INTEGRATED PROJECT AS A PROJECT METHODOLOGY

In the office of Richard Rogers, in the Anglo-Saxon tradition, integrated design is used to manage the resident multidisciplinary team, so they are able to control surprisingly well the various issues related to building construction. Besides the traditional constructive solutions, they try to respond to various environmental requirements by perceiving the building as a complex organism. See, for example, the amazing work done by this team at Barajas Airport (Madrid). Colour, lighting, natural ventilation, spatial organisation, are all worked in an integrated manner with the goal of creating a single organism.

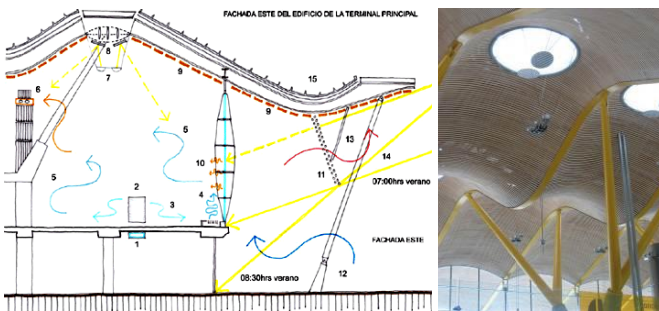


Fig. 6 Madrid Airport, schematic cross-section (Powell 1999)

Fig. 7 Madrid Airport photo by the author

Although our purpose now is not to reflect on the power of this close relationship, it is inevitable that from the start, all the professionals related to Construction, in particular the designers, have this holistic view of the building as an integrated system of multiple disciplinary systems. It is therefore essential that this methodological stance of each team member starts early on, from their initial years of training, because it is clear that not everyone will have the opportunity to work in teams of such excellence as those that have been mentioned. In his book, "Building Systems Integration for Enhanced Environmental Performance", Shahin Vassigh and Jason Chandler referred to the benefits of an integrated practice.

"(..) have created substantial shifts in the professional role of the architect, the education of architects, the innovations of building design, and the accountability of design decisions" (Shahin Vassigh and Jason R. Chandler 2011)

Design is less and less intuitive and increasingly scientific - light, colour, acoustics are measurable "material" and assessable against defined standards set for buildings. The building is now designed to respond to certain very specific and quantifiable goals.

The basic design of a building is governed by rules set out by the designers. These rules are the response of each discipline to the requirements of the brief and the established regulations. Each discipline imposes a set of rules articulated by the integrated project. For example, the rules imposed by the thermal or acoustic engineers are definitive in the design of the building system.

The expertise in each disciplinary area has been steadily increasing in order to meet all the performance demands that apply not only to buildings but also to the effectiveness of the construction process. Moreover, taking into account the universal concerns for sustainable construction, the responsibility imposed on the decision-making process has been increasing exponentially:

“As the environmental impact of buildings becomes increasingly recognized, the role of building designers and the initial decision-making process, which determines materials, systems, and construction processes, becomes more critical” (Rush 1986)

Since it is the architect who is responsible for the coordination of all the systems, he is also responsible for the coordination of the integrated project. What would an exhibition hall, which should be neutral enough to host any exhibition, be, if there were no physical control of the location and integration of the electrical and mechanical plants, if it were not coordinated by the architect?

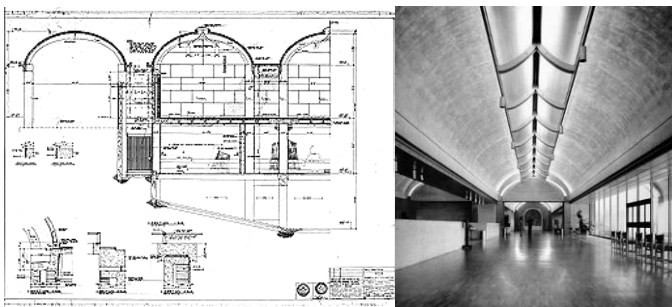


Fig. 8 Louis Kahn, Kimbell Art Museum (Louis Kahn)

In Anglo-Saxon countries, in particular, the Integrated Project as a methodology is researched in-depth. The concept of integration is understood not as a stylistic architectural current, but as a method of organising the steps and players involved in developing the design and the construction process: a working methodology.

“Integrated Project Delivery (Architects) is a project delivery approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication, and construction. “ (Architects 2007)

Within RIBA, they are seeking to create procedures and tools that systematise and optimise the designs of the different specialities and the relationship between the decisions of the various disciplines. The Architect's Handbook of Practice Management (RIBA 2010) is part of the library of every British design office, both architectural and engineering. In the U.S. in particular, the topic of the integrated design in architecture has become part of scientific research at university level. In his book, *Integrated building, the systems basis of architecture* (Bachman 2003), Bachman points out the advantage of this integration:

“This linking role of integration helps us understand design and technology as complementary opportunities rather than conflicting values.(...) in a sympathetic way and emphasizing the synergy of the parts without compromising the integrity of the pieces.” (Bachman 2003)

The focus of this methodology lies in frontloading the work effort to the design phase, as shown in the Macleamy Curve. There are substantial differences when the effort in each phase of the design and the construction process in a traditional design methodology is compared with the process using integrated design. As in the IPD the project is brought to a deeper level of detail, the possible changes in the construction period are significantly lower, which translates into a lower overall investment.

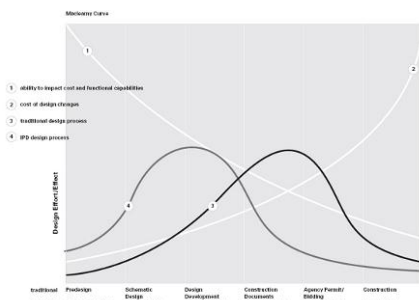


Fig. 9 Macleamy Curve (Architects 2007)

Information technology tools are insufficient to establish these relationships, so it is essential that future architects and engineers are made aware of the importance of the decisions of others to substantiate their own solution. It is therefore inevitable that there is a huge methodological complicity between the various designers in finding this joint response.

4 THE ARCHITECTURE MODULE AT FEUP

It is the responsibility of the "Architecture" module, in the 2nd year of the 1st Cycle of the Master's Course at FEUP to show future engineers the inevitability of the Integrated Project in the development of any project these days. They are taught to understand how the choices made by each discipline at various stages of the design and construction process can contribute to the functioning of the project team and even the performance efficiency of the building in service.

Whether in the theoretical or the practical component of the course, the language of architecture is gradually assimilated by students through the interpretation and investigation of constructive technologies, particularly those associated with structural systems. In lectures, the illustration of concrete cases from architectural

history allows them to learn design methodology as an integrated disciplinary project; and in practical classes, through the analysis of specific projects, the preparation of drawings and even model-making, students are able to access the work tools available, from project design to construction.

4.1 Objectives of the Architecture module

Basically, the objectives of the module are focused both on learning the technical dimension integrating all the activity that takes place in the production of Architecture and Construction, and the development of the students' critical and analytical ability when it comes to architecture, encouraging them in their reading and basic grammatical interpretation. The objectives therefore fall into two groups:

a) Technical formative objectives, including:

- To convey a good, thorough understanding of Architecture as a creative act and as a system of subsystems, as well as its role in the practice of building in Portugal;
- To develop the ability to read/interpret architectural designs, through the assimilation of the specific language of technical design for the representation of architectural projects, and of spaces in general;
- To encourage students in the procedural principles that structure architecture design (hierarchy and its constitution, phasing, regulatory implications, joint policies in residential construction, etc.), as well as in the effective articulation between professional civil engineers and professional architects;
- To reflect on the challenges of architecture in the context of new European regulatory requirements;
- To demonstrate the importance of the factors that contribute to good performance by the Civil Engineer in Architecture and Construction activities;

b) Critical formative objectives:

- To assimilate the analytical course of architecture in interpreting the historical evolution of architectural space, articulated with constructive and structural practices and innovations;
- To provide a framework for a review through monographs of the major movements and works of architecture up to the present day, in order to expand the horizons of the Students at cultural, architectural and aesthetic levels.
- To define the professional skills required to work in multidisciplinary teams, work that is characteristic of the professional builder and architect.

4.2 Skills and learning outcomes

The core skills to be achieved are:

- **Knowledge:** Describe the main concepts of architecture and its subsystems and identify erudite and vernacular construction techniques, as well as the principles underlying the creation of architecture throughout history;

- **Understanding:** Manipulate and interpret written and drawn elements that are part of an architectural project. Identify the codes of representation and the techniques for designing building elements, and link them judiciously to structural and non-structural parts, identifying them and distinguishing them from each other;
- **Implementation:** Establish procedures for categorising the various conceptual and constructive solutions in different periods of architectural history up to the beginning of the 21st century, in order to identify new interpretations of architectural spaces,
- **Analysis:** Compare and classify the results of research on the set of structural systems of architecture and current strategies to solve problems relating to energy, the environment, etc.
- **Synthesis:** Systematise new ways to build today's architecture, exploring the new forms of living and of mixed use;
- **Evaluation:** Assess the procedures and practices used. Critically re-examine recent techniques, recommend possible improvements in construction practices and in the implementation of new methods for construction.
- **Engineering Design:** Identify sources of technical and scientific literature and their applicability in the national and European context;
- **Research in Engineering:** Identify the various sources of technical and scientific references and their applicability in the national context;
- **Engineering Practice:** knowledge and contact with public and private entities, questioning the practice of architecture and the articulation between engineering specialties and architectural design. At this point it is worth mentioning the opportunity to conduct technical visits to paradigmatic works supported by the designers directly involved.

4.3 Interdisciplinarity in the academic context in the Architecture module

The module derives its academic emphasis from the interdisciplinarity possible in the 1st cycle of the MIEC. In this sense, it takes advantage of the learning taken from the modules in the first two years, but particularly Technical Drawing and History of Civil Engineering (both in the 1st semester of the Year 1), Topography (2nd semester, Year 1), Engineering Geology and Environmental and Social Impacts (both in the 1st semester, 2nd year).

Thus, we are sure of the effective contribution of the Architecture module in achieving the goals of the Masters in Civil Engineering, while still contributing in the 1st cycle to the training of future Civil Engineers capable of "(...) *conceiving, designing, and managing systems, Civil Engineering structures and works, applying suitable and up-to-date analytical methodologies, materials, equipment and processes, with respect for Ethics, the Environment and the highest interests of the Community*" (Alves, 2012). The module is fully aware of scientific and technological innovation, aiming at a balance between the built environment and the natural world.

5 THE PRACTICAL COMPONENT

Alongside the theoretical classes, in which a reading of the history of architecture is made through the technological development of construction, particularly the articulation between architectural language and different construction systems, in the practical classes, specific projects are studied, looking for this common language in the various disciplines of design.

Considering that Civil Engineering students may go on in their careers to develop M&E projects, particularly for buildings, such practice will involve the need to effectively articulate their solution to that advocated by the architect and/or other designers. It is therefore essential that during their training students acquire the ability to read and interpret different architectural projects, thus becoming acquainted with the specific language of technical representation drawings, an essential skill in the act of creating and designing built structures and spaces in general. The students are therefore given an introduction to the concepts of STRUCTURE and COMPOSITION, reflected in the context of standardised forms and spatial systems.

In the first assignment, the general drawings of an architectural project being implemented are studied, focusing on its technical drawings, plans, sections and elevations. By analysing these designs, the aim is that students assimilate the technical representation codes for the various architectural components (wall, floor or pavement slab, pillar, beam, load-bearing wall, roof, stairs, ramp, vault, lintel, arch, etc.); the importance of the hierarchy of drawing lines (object, hidden, centre, dotted lines), and their meaning (line of sight, section line, elevation line, reference line, line above the section plane, shading, hatching or marks). After this interpretation, students are asked to organise this information in a subtitle graphic by specialty project.

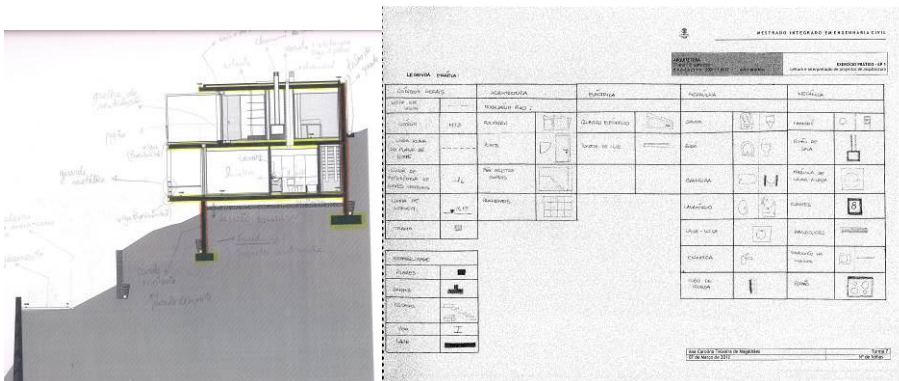


Fig. 10 Drawings made by students for the Architecture module in the Masters in Civil Engineering 2012/2013

The aim of the second assignment is for the students to read and interpret an architectural design and the respective work as built by analysing the constructive system adopted, in order to gain an understanding of how the technological options determine the formalisation of the building. The exercise is conducted in a group and individually. Initially, each student reads the information provided alongside the drawings and pictures of the finished structure, with the aid of drawings made to study the structure, the form and the space in the building. In the second phase, the group must organise research into literature that complements the constructive analysis of the building, allocating the research between several students, and addressing the following topics: Historical analysis of the structural system; Research on similar buildings; Design principles; Constructive methodology.

Using the information collected by each student, the group must prepare a new reading of the project, pointing out the specific design solutions. The conclusions drawn from this analysis should be the point of departure for the group to make a model for the final presentation. The aim of this phase is for the students to understand not only the potential that the development of the model offers for the understanding of the project, but also to have an approach to the constructive methodology of the system studied.



Fig. 11 Models made by students for the Architecture module on the Civil Engineering Integrated Master's 2011/2012

The third assignment offers an approximation to the real context of the design and construction process, through the analysis of a building that is completed or still under construction. This time the aim is that students are able to interpret the architecture in the light of the disciplines of Civil Engineering; Acoustics; Thermal; Fire safety; Stability; HVAC; and Hydraulic infrastructure.

Every year we try to find a work that is easy for students to access, that will encourage them to develop an interest in contemporary buildings, providing them with an opportunity to get to know them relatively easily. We also ask the designers of the building in question to get involved in a major way in the development of the work with the students.

In the first class, students make an interpretation of the architectural and structural designs and others provided. In the second class, we promote a discussion with certain members of the design team: the architect, the project manager, the structural engineer, the mechanical engineer and others, who explain their projects to the students. In this class, students have the opportunity to understand how the team and the coordination between them all works in order to achieve the INTEGRATED DESIGN. In the next class, the designers make a guided tour of the building with the students.

Back in the classroom, with the prepared data and analyses, the group interprets the work according to one of the engineering disciplines, looking for the rules that this discipline has imposed on the design of the building, on its functional and programmatic definition, on the spatial and dimensional definition, on the definition of its performance and its construction. The final phase of the assignment consist in the synthesis of all the information gathered and prepared, expressed in a poster to present to the class at the end of the work.

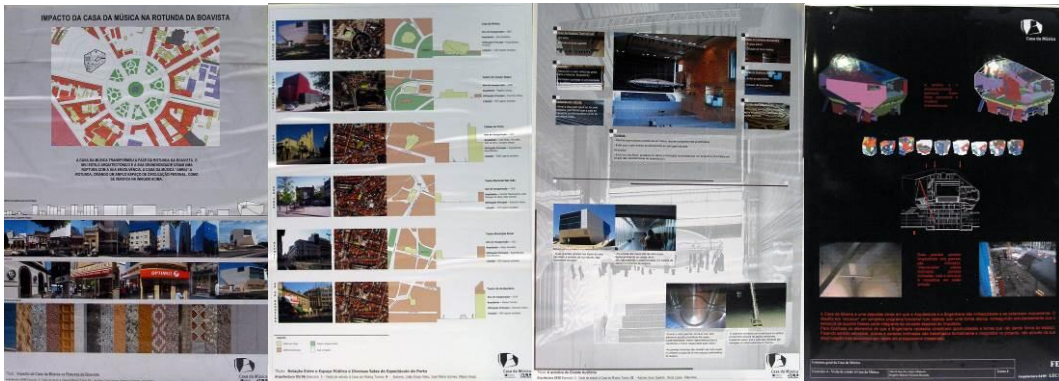


Fig. 12 Work done by students for the Architecture module for the Masters in Civil Engineering, 2005/2006

To finish off the semester, we show in the last class the possibilities that the sketch can offer them in communicating their ideas and testing the solutions they will look for in their future careers as engineers. The main objective of the exercise is to develop the students' ability to communicate through quick drawing (sketching), recording and memorising the points of special interest to retain along the way. They follow a set course through the college facilities, drawing the main points in quick 5 to 10 minute sketches.

At the end of each semester an exhibition of the work done is held in the Department of Civil Engineering. It is an important opportunity to show the academic community and future students of the course the potential of this interdisciplinarity between the various people involved in construction, the positive outcome of the joint methodology for designing a building, the INTEGRATED DESIGN PROJECT.

6 CONCLUSION

Not so many years ago, construction work was a laboratory of ideas that were studied in the office and fine-tuned with the craftsmen who were doing the building. Architects and engineers learned to discover the secrets of construction during periods of work experience. They made contact with other disciplines, paid visits to construction sites and learned from the experience of their seniors. In designing a window frame, they would consult the thermal engineer, but also seek the approval of the carpenter, the contractor and the glazier. Construction was learned on the job. However, this knowledge of CONSTRUCTION that was acquired over time, by getting their hands dirty, is no longer possible.

Since today there is no longer sufficient time nor construction sites to ensure that future engineers and architects gain experience on the ground, both must be shown the importance of the decisions of other disciplines for the consistency of the solution that each presents. The participants in the design must be aware from early on that each of their projects will be part of a unique solution in building an INTEGRATED PROJECT. Colour, lighting, natural ventilation, spatial organisation, are measurable and assessable, to be worked in an integrated way with the goal of creating a single body, the INTEGRATED SYSTEM.

It is time to look at the DESIGN OF CONSTRUCTION as a total solution bringing together various DISCIPLINES, to adopt a design methodology that can articulate the necessary information between them. An INTEGRATED STRATEGY that jointly seeks the solution to this equation. Taking advantage of the

expertise of each specialty will surely lead to design solutions found collectively in a more creative and effective way.

REFERENCES

- Abrantes, Vitor, Bárbara Rangel, José Amorim Faria e João Pedro Poças Martins. 2009. CdO 01 cadernos d'obra revista científica internacional de construção. Porto: Gequaltec.
- ———. 2010. CdO 02 cadernos d'obra revista científica internacional de construção. Porto: Gequaltec.
- ———. 2011. CdO 03 cadernos d'obra revista científica internacional de construção. Porto: Gequaltec.
- Alves, Fernando Brandão. 2012. "Mestrado Integrado em Engenharia Civil - disciplina de Arquitetura". Acedido a 22/4/2014.
- Architects, The American Institute of. 2007. Integrated Project Delivery: A Guide. California.
- ARUP. 2009. Random Structural Generator. Ed. Figure A - Random Structural Generator. NY: Cadernos d'Obra 03.
- Bachman, Leonard R. 2003. Integrated Buildings - The systems basis of architecture. New Jersey.
- Louis Kahn, Architect. 1970. Kimbell Art Museum,
- Fort Worth, Texas. Pencil on Paper, Em Copyright 1999. The Alexander Architectural Archive. The University of Texas at Austin.: Preston Geren, Associate Architect
- Pencil on Paper.
- Powell, Kenneth. 1999. Richard Rogers: complete works London Phaidon.
- RIBA. 2010. Architect's handbook of practice management. Vol. 8th ed, Royal Institute of British Architects. London: RIBA Publications.
- Rush, David. 1986. The Building systems integration handbook. American Institute of Architects.
- Shahin Vassigh and Jason R. Chandler, Shahin Vassigh, Jason Chandler. 2011. Building Systems Integration for Enhanced Environmental Performance J. Ross Publishing.