The Importance of Circular References, Architectural Modeling, Digital Project and Collaborative Actions in the Architecture Learning

Ivan Xavier(✉), Philipe Cantreva, and Igor Klein

Universidade Federal Fluminense, Niterói, RJ 24210-240, Brazil
ivan_xavier@id.uff.br, {pcantreva,nielkigor}@gmail.com

Abstract. This article presents the potentialities of architectural modeling in the learning process of Fundamentals of Structural Systems Modeling subject—EAU (Escola de Arquitetura e Urbanismo), incorporating new learning methods, making use of circular reference processes. The low quality of the projects in terms of design, representation and compatibility are still the major problems in architecture. Despite of CAD, BIM and other modeling softwares, mistakes have been detected in many types of projects (architecture, structure, building facilities, etc.). The origin of these occurs in a systematic way, due to the lack of knowledge of the structural and digital possibilities, associated with the non-valuation of the modeling systems and the collaborative actions integrated in this process, which can be already experienced at the beginning of the future architect's education. The experiences and the tasks performed demonstrate that this combination reinforces the theoretical concepts, enhancing significantly the creative potential in integration with the learning of structural systems.

Keywords: Modeling · Digital project · Collaborative actions

1 Architectural Scenery

In the architectural scene, from the last decade of the twentieth century, as a result of the introduction of new tools based on digital technologies, projects with particularities in the production system begin to emerge. Parametric design, digital manufacture, automation, the application of responsive systems and the possibility of simulations become powerful instruments of technological innovation, which are still capable of transforming the guidelines of the current processes of representation.

Easy access to the state-of-the-art equipment which has not yet provoked in the academic environment the experimentation of processes with these technologies, with the scope and potential of altering the architectural and urbanistic discourse of teaching. Universities have opened what we can call a "technological island" with differentiated design laboratories and state-of-the-art appliances which make up a creative environment, offering courses in the area of design, technology and management. These laboratories also offer graphic design, service design, relationship marketing and design thinking, with the specific objective of learning in a practical and

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accessible way the technological innovations, which is a must for the expansion of the universe of architectural design.

There is an awareness that the understanding of this new tool is capable of influencing and altering the design capacity, modifying the processes of representation and use of materials, as well as reformulating the productive process and the understanding of the architectural form.

This reality sets a challenge in current teaching and research systems and offers us the resources to define a new language of learning in architecture. Some of these topics of interest surround us and we are aware of their importance. The study of parametric design, generative design, digital manufacture, parametric modeling, responsive design, human-robotic interaction and simulation environments is a priority in the design process.

There is a still rarefied and slow discussion in the sense of incorporating these processes in the environment of the school of architecture and urbanism, especially when these resources are not part of the academic reality. The challenge was to implement a method which we called "*circular references*", which allows the development of a new methodology of architecture teaching that uses the multidisciplinary of instruments associated with collaborative actions that generate creativity and that feed themselves back.

2 References Circulars

The exercise of **Circular Teaching**, with the application of circular reference method, has as its first purpose the students contact to the structural problem associated with the design creativity in the conception of the architectural project.

In the course of the EAU (Escola de Arquitetura e Urbanismo), there was a curricular reform in 2014, in which new subjects were implemented, in order to facilitate the understanding of certain contents that were previously seen in an abstract way. The subject of Fundamentals for Modeling of Structural Systems was incorporated to the new grid. Its methodology consists in the achievement of sketches, mock-ups and digital tools which promote creativity and allow the student to understand the operation of the structures and how the loads behave in the same, after understanding the theoretical concepts.

This first reading and the contact with the theory of structural systems introduces the student the discussion about the learning process of how the structural elements act on the architectural project, considering the production process and creativity, based on the student's perception of the structural systems. The reading includes the recognition and observation of the existing architecture, considering all the elements that make up the building, its conception, its implementation, the understanding of the structural system and the use of all the elements that make up the building.

Another objective inserted in the exercise is the expression of several forms of registration and understanding through the drawing and the possible languages of representation of the architectural object inserted in the urban environment.

In order to reach the expressed programmatic objectives, the adopted didactic strategy considers that the student needs, initially, to learn how to look at and recognize

the constituent elements of the building. This observation must evolve towards the application of the various forms of experimentation in the creative process of the project associated with the application of the structural system. Several activities are planned in the various classes, including field surveys through drawing, graphic representation, making mock-ups, modeling with various materials, electronic models, lectures and interactive seminars.

The task of each student, sometimes working as a team, or individually, is to produce in each class the theme of the proposed exercise, using creativity together with the understanding of structural systems. The representation of this information is made through the diversity of materials in the production of the mock-ups always associated with the drawing. The expression is free and so is the choice of materials and language.

Parallel to this work of constructing models and projects, students are encouraged to seek information and references from similar works by professionals in relation to design decisions from the point of view of structure and architecture.

The experimentation consists of demonstrating how the mechanisms behave and their different types and techniques, in architecture teaching, from the theory of the structural systems of buildings [1]. The technique starts in several ways, and there is no previously defined model. Circular references are the inspiring sources in this process, and can begin with a video presentation of an architectural work, (Zara Hadid Architects—Edificio Bee'ah) or a video demonstrating the potential of the application of bamboo (Elora Hardy: Magical houses, made of bamboo—TED) or simply provide a CAD Project (Casa Y—Chita, Aichi. Japão). These examples can be exploited for the development of structural system modeling, for the elaboration of models of re-reading of a certain architectural project or just to observe and to draw the architectural model in the field.

According to Sennet [2], the architect Renzo Piano explains his method of work as follows:

> We started making sketches, then we drew a drawing and then we make a model, then come to reality - let's go to the space in question - going back to the drawing once more. We establish a kind of circularity between the drawing and the concretization and back again to the drawing. About repetition and practice, notes Piano: It is perfectly characteristic of the artisan's approach. At the same time, we think and do. We draw and do. The act of drawing (…) is revisited. Do, redo and do it one more time [2].

Circular references or circularity help in this process. "The fear of making mistakes is vitally important in our art … to achieve this goal, the work process must do something that does not please the organized mind: to live temporarily with the mess" [2].

The activities are continuous in the classroom, in the laboratory and in the field, each week a new challenge. The product of each student in this stage seeks a personality of his own, a trademark, a new and inspiring design. If our activity were only guided by the CAD, we would be remounting some basic problems connected initially by the underutilization of the software, such as understanding problems between the various stages of the project and the limited vision of the image on the screen, with the zoom effects which hide the problems and the design flaws.

We can also cite the different points of view by "rotating the image", the precision failures by insertion of the reference points that apparently may be correct, but that in the zoom detail shows us imprecision. Another relevant factor is the disconnection that

involves the evaluation of the proportions that are presented on the screen of the designer by the handling of the possibilities of use of different scales and that will never be replaced by the observation of someone who is in the field, who executes the drawing and who constructs the model, that is, what appears on the screen represents solutions that will never be seen in the tried-and-tested view of the field and the model.

The experimentation of circularity in the collective environment of the classroom, laboratory and field enables interaction and exchange between individuals, at the level of the experience and results. The final work requires the model, the digital and verbal presentation, the knowledge of the structural design theory and the architectural and bibliographic references, besides the registration of the whole process of achievement. All development is interactive and the creation of groups generates knowledge and innovation.

The development of this methodology comprised four basic stages in the process called Circular Teaching: *Entrance, Initial Activity, Repertorial Amplification, Use and Experimentation*. These steps are necessary to the learning and the success of the project. In the step *Entrance* we have the initial and informal repertoire of the student, in the stage *Initial Activity* we have the presentation of the object and objectives of the menu of the discipline and the theory related to the object of work. In the *Repertorial Amplification* the presentation of the theme of the exercise for the structural systems through presentation of videos, consulting to sites and bibliographic research is carried out; in the sequence is a visit to the field is done—which can be a museum, a facility, the university campus, etc; buildings that exemplify the various structural systems. In the Use and Experimentation, we elaborate a sequence of drawings according to the repertoire acquired in relation to the theory presented associated with the elaboration of manual modeling, or in reverse, we can start with the manual model and then with the drawing.

This decision is taken collectively, and/or activities can occur simultaneously—there are no rules. At each step we can introduce a new tool, an unusual material and a new challenge. In this phase, we also perform digital modeling, with the use of digital representation applications (SketchUp, CAD, Revit, etc.), the system can also be inverted, we can start with the digital tools, going through the modeling and concluding with the drawing. In the stage of *Use and Experimentation* the output of the various products occurs, which could be done by an individual, in group or collective, depending on the definition of the theme and the theory to be experienced.

The work scenario is created based on the collaborative actions developed among all members of the process (Fig. 1).

3 Collaborative Actions

In the development of ***Circular Teaching*** the fundamental and most important approach is the exchange of experiences among all participants, where the use of the instrument is of free choice and the modeling and graphic materials are also free. At present, the use of Collaborative Actions is already a consensus in groups of professionals and companies that share knowledge about a certain specific area and / or problematic situation, and participants hope to make improvements based on what they

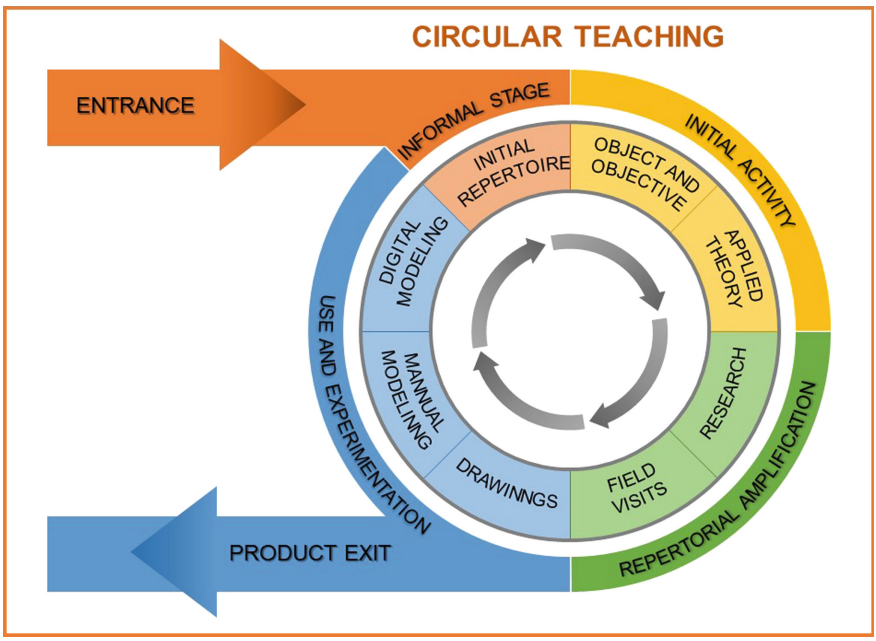

Fig. 1. Circular Teaching, learning steps through circular references

have learned from the group [3]. The sharing of knowledge through benchmarking is fundamental for the development of indicators, allowing comparison of performance, sharing practices related to the design process management processes and indicators in the actions related to architectural design, construction and sustainability.

The creation of collaborative benchmarking groups can be focused both on the participating individuals and on the companies and institutions. In the design process for example, through social networks on the internet it is possible to receive: suggestions of useful ideas for the conception, necessary for the creation process; forms and models of representation, technical design elements, technology to be used, systems of planning, management and sustainability.

The collaborative actions allow the constitution of all the activities inherent to the creation of all the necessary infrastructure, for the appropriation of local materials, efficient systems for building solar equipment, alternative sanitation systems, recycling and water supply, reuse of waste from the construction industry and processing of local raw materials, as well as innovative models for the acquisition and sharing of knowledge.

In collaborative benchmarking groups it involves designing intelligent design, implementation, and evaluation projects. With the adoption of these actions, associated with the modeling process, digital graphic representation and technological development generate knowledge and innovation in a way that they provide transparency to the process, establishing an open, egalitarian and trustworthy environment for exchanges and, above all, it engenders commitment among participants. The teaching that uses processes with the accomplishment of tasks in group and by means of collaborative actions is already used in other academic environments.

The University of Architecture and Urbanism of São Paulo uses the process to incorporate reading, perception and representation of the configuration of the city, the understanding of the constitution of its buildings, environments, landscapes and its determining elements, and to introduce the discussion of the processes and agents which produce urban space in the city of São Paulo.

The task of each team was to raise the longitudinal profile on both sides of the course, recording the constituent elements of the city in integrated work, where the representation is made in a single drawing on elongated paper, where the main focus of expression is the student's impression. In the exercise the expression was free and so was the choice of language. Parallel to this work students are encouraged to seek historical information, demographic and socioeconomic variables through the exchange of information and experiences. The example shows us through the images the process of using the exchanges and experiences demonstrating the importance of the collaborative actions (Fig. 2).

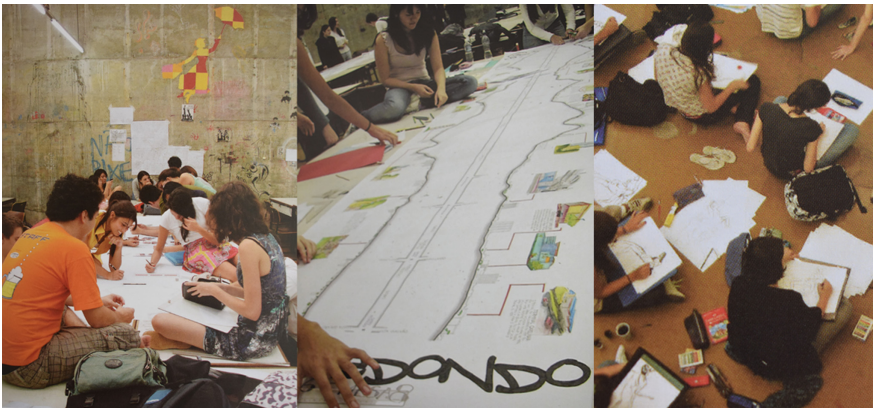

Fig. 2. Teaching using the process of group tasks through collaborative actions—FAU-USP

4 Architectural Modeling

The study of structural systems in the architecture course presents gaps in the understanding of its main concepts and in many cases does not incorporate the creative processes for this learning; the structural calculation and the mathematical references are introduced to the students of the first term in a subject taught by the Engineering School. In this way the work of Engel [1]—Structural Systems, with the presentation of the mechanisms of active form, active mass, active surface, and vertical structural systems was the inspiring theoretical source for students who wanted a new methodology in learning the structural systems in the EAU (Escola de Arquitetura e Urbanismo).

Experience through modeling has shown to be more promising in terms of understanding how shape affects structure and how structure affects the shape, and how the deformations will occur due to the active loads, compared to traditional teaching.

The understanding of structural concepts allows the student to produce models of different forms with safety, skill and speed, providing several advantages in the learning process, such as understanding the behavior of the set of structural forces.

As Rebello said: "But what is the structure after all? … the structure is found in all areas of human knowledge and can be understood as "A set of elements—slabs, beams and pillars—that are interrelated—slab supporting beam—beam supporting pillar—to perform a function [4].

For the learning of the structures, the achievement of drawings, models and the graphic interpretation of projects in digital platforms aims to show how forces act within that system and possible solutions to support possible problems without losing the proposed architectural party.

In this sense it is possible for students to learn in different ways that a project can take, depending on the program to be followed, the best structural proposal and the aesthetic definition. In a complementary way the students of the first term rely on the content of the subject of Geometric Representation Systems which is fundamental to the understanding, and perception of forms. Thus, in the systematic teaching of structural systems, the concepts of collaborative actions are added through the sharing of experiences in the collective environment, contributing to the improvement of performance.

Addressing the integration of modeling, digital design and collaborative actions as a new tool for thinking about architecture and structural systems, not only as separate systems, but integrated as Rebello states:

> Most of the time, teaching the structure presupposes that there are two learning strands: architecture and engineering, being seen, however, as a great misunderstanding, since there are not two separate studies for this same subject, and there is perhaps only a difference of profundity [4].

5 Bibliographic Review

The bibliography related to the article finds in Engel [1]—Structural Systems the greatest theoretical basis for the accomplishment of this work. The work describes in detail the main structural systems (active form, active vector, active mass, active surface and vertical structural systems) and how their understanding contributes to the teaching of structural systems.

In this literature several examples are demonstrated in the five systems. Besides the theoretical concepts, the work demonstrates through graphics and images how the structural forces behave, Engel [1] bases the systematic basis of learning by explaining what is meaning and function, making it clear that structure occupies in architecture a position that performs two functions: granting existence and sustaining form, evidencing that the agent responsible for architecture, its design and its accomplishment is the architect. The author also reports that the architect should develop the concept of structure for his projects in professional language.

Engel [1] presents the hybrid systems, combined with coupling systems. At the conclusion of the book the structural form is described, conceptualizing the geometry and the image of forces, the folded and flat surfaces, the simple curved surfaces in dome or saddle.

The examples of force images and graphs were experimented by the students in the modeling process carried out in the classroom, that is, the practice verifies the theory and the proof is performed in the application of the work.

The text of Rebello [4], in relation to structural design and architecture, provides an overview of the relationships between structural materials (wood, steel and reinforced concrete) and the several variables of its use, such as active efforts, forms of the sections, form of obtaining and applications.

Another relevant aspect of the book is the pre-dimensioning of the various structural elements, as well as their behavior (arches, beams, trusses, pillar, slab, cable join, vierendeel beam and pillar, vault, dome, folded plates, etc.), application and usage limits.

Regarding applicability, the author clearly defines the limits around the intervals by means of pre-sizing tables which help the student to understand the points of application and of maximum and minimum sizing.

The tables are constructed to facilitate understanding and visualization of the compatibility between the structural systems and the various materials. Another interesting aspect is the various possibilities of association of constructive elements by means of several intersections between the various elements, with simpler and more complex internal associations and/or concrete arcs associations. Another possibility is the use of steel or wood, with steel or wood trusses and integration with cables.

The work of Rebello [4] is an important reference for the student who is beginning the studies of structural design and architecture, revealing the importance of the understanding and applicability of pre-dimensioning, showing the constituent elements of the systems as formators of the architectural compositions.

In the text by Hernadez-Ros [5] "What is structure?" the debate is expanded about the structure and architecture as the science of structures and the origin of the scientific treatment in relation to the structural problem, the structural requirements, the resistant structure and the design of the structural forms of the buildings and their complexity: "The desire to draw structures with the smallest possible volume of material generally leads to complex drawings" [5].

The author presents the surface and three-dimensional geometric models, establishing the relations between space and movements and their respective deformations. Finally, Hernadez-Ros [5] guides the analysis process, that is, checking whether the structure and each of its parts is in equilibrium. This stage is crucial because it instrumentalizes the modeling system with an important reference for understanding the structural systems.

6 Creative Potential

The application of modeling in collective activities in the classroom is the crucial moment for the true understanding of the theoretical content that the student experiences. It is through the chosen materials, the graphic design of the project and the way the moorings, articulations and the fixation of the project to the base are made that the architectural form is organized in the available space, following the proposed structural parameters.

The elaborated model serves for the student to verify the stability and the efficiency of his or her project. It is the moment of tension, experimentation and fear. The finding made in the environment is characterized by apprehension and many students believe that the product will not leave the paper. Circularity draws, experiences, cuts, redesigns, and constructs several times—fear is eliminated and creation emerges! It's the Rapture!

It is an intense trial and error exercise that happens due to the distribution of forces throughout the created system, considering that the simulated loads in the models will behave differently, according to the type of structure studied. In this way, the subject provides a basis for how such forms behave in real construction.

It is of utmost importance, therefore, that anyone concerned with the design of structures should have the ability to visualize how a structure will behave in a given circumstance scenario, and how the shape of the structure will influence this behavior. The student should develop an intuitive feeling for structural behavior so that all important choices are taken correctly as to the structural form to be used. The satisfactory outcome of a project in terms of aesthetics, economics and safety depends on this important decision [6] (Fig. 3).

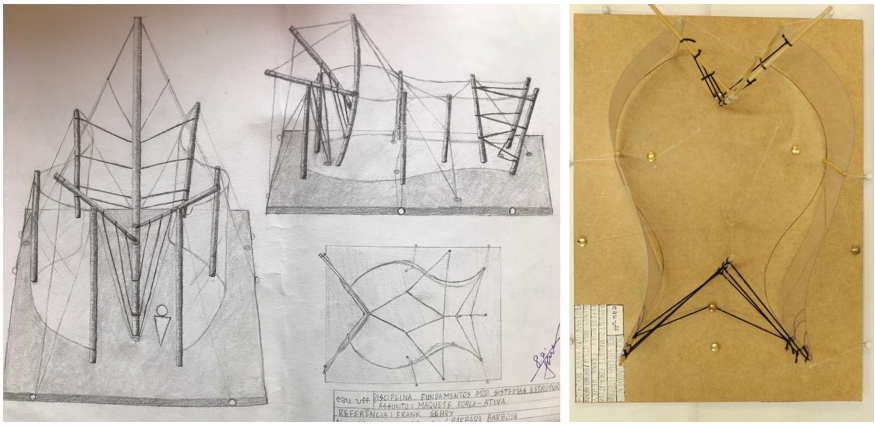

Fig. 3. Drawings and mockup elaborated from the first exercise—active form

From the selection of a project with free search on the internet of the images and the supply of the electronic project in CAD, the challenge proposed to the students is the constitution and the understanding of the structural systems from the data provided in the sense of the constitution of the structural system (Fig. 4).

The first difficulty was the handling of the CAD system, since the defined project did not contain parameters and dimensional information and many students of this first term were not aware of how to use the digital system; this difficulty was eliminated with the guidance of the tutor of the subject initializing the student to the virtual production environment. Once the initial stage of understanding the project and the own design dimension, the conceptualization stage of the structural system began and how the project author was able to solve the structural problem with the form and material used in the construction (Fig. 5).

Fig. 4. CAD interpretation, understanding of the project, structural conceptualization and elaboration of the model

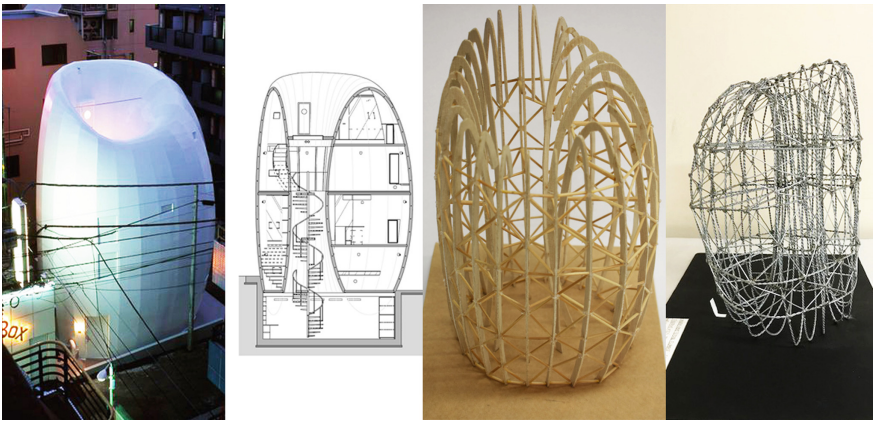

Fig. 5. Research of the architectural project, understanding of the project, structural conceptualization and elaboration of the model

The understanding of these aspects enabled the students to develop the next stage of the work, with the construction and modeling of the referred project on an appropriate scale which clearly demonstrated the structural system of the building. The modeling activity associated with the design and understanding of the digital language allows breaking down barriers of structural and architectural complexity through the circularity of the various activities for the architect's design.

The elaboration of the works by the majority of the students occurred by means of the experimentation of the circular references presented through the understanding of the project, from the digital graphic and its consolidation in the modeling through the experiment in the models. The various attempts complemented by the theoretical debate on structural systems and their design associated with collaborative actions

between the participants of the group contribute to the creation of a model of the referred project, with clear and adequate structural characteristics, consolidating the learning.

The experimental attitude, the repetition at each stage and the application of the five structural systems proposed by Engel [1] consolidate the experience and the systematic advance generating new possibilities of creation. The creative aspects are materialized with the new structural forms where we can prove in the model the structural requirements: strength, rigidity and stability.

The experience is completed when the groups involved in the work design they conceive the models with differentiated structure, verifying the possibility of applications with other materials, improving the quality of the design and the model.

7 Conclusion

The introduction to the students of the concepts of structural systems through the **circular teaching** method and the multiplicity of tasks in the collaborative action environment, based on theoretical references, stimulated learning in knowledge of structural systems; associated with the concepts of Engel [1] brought about creativity in the subject of basis for Modeling Structural Systems of the EAU.

The experience and freedom with which the exercises were performed provided an environment proper for the students to discover their potential through the different forms of experimentation at each stage. The results seen by the production of the models and the final presentation of the works demonstrated the process of development, thus sowing the student's progress in relation to their creative potential and their initial repertoire.

The resistance to the learning challenge of the structural systems was surpassed by the diversity experienced in the classroom and in the field. The fear disappeared and the circularity of the processes made new discoveries and talents possible. Leaning on the act of repetition and experimentation with diversified materials, the experience generated knowledge and motivation. We read, we design and we do. The act of designing and learning is revisited.

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