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DATA and Information in Architectural Design Process Through Building Information Modeling: A New Epistemological Horizon of BIM Methodology

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This paper takes up the results of two research projects led by the authors: Contemporary Architecture in Colombia and Optimization of building management through the implementation of digital twins. These results are applied to a pedagogical investigation on the work developed in an architectural design workshop. The experience of the Architecture and BIM workshop of the Universidad de Bogotá Jorge Tadeo Lozano (UTADEO) is presented. This academic space, which responds to some challenges of the implementation of the BIM building information modeling in university education in Colombia, uses BIM methodology to train the student in architectural design competencies. It highlights the one corresponding to the integration of the technical dimension and its impact on space design decisions.

The experimental exercise in the workshop seeks to transpose the methodological and technological advances derived from the digital transformation of the industrial sector to the training processes in the academy. This strategy links the information modeling of the building as a method to generate a change of the projective thinking and to improve the decision-making for the production of architecture.

In the second part of the article, on section four, from the results of the workshop experience, we proceed to discuss the digital interface where data and information collide and the architecture teaching model in Colombia and to outline a new, more appropriate and current epistemological point of view for architecture education.

This exploration of the ʻdata' theme in architecture design process through both a practice-based and a theoretical approach suggests a prospect for the future professional practice and its associated training processes. The possible widespread implementation of these new ways of projecting can lead to the development of a new epistemological model

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for architecture education in Colombia, in accordance with disruptive practices such as the design process under the influence of digital transformation.

1. Introduction

The Building Information Modeling (BIM), as a methodology for the development of projects, is a set of collaborative processes supported by industry 4.0 technologies (Sukhodolov, 2019). These processes allow the integrated development of projects through the information modeling of each phase of their life cycle, managed through a common data environment and the use of open standards that facilitate continuous collaboration between different agents and disciplines. Therefore, the evolution of BIM information modeling must be framed within a paradigm that takes into account people, processes, and technologies in an increasingly interconnected world (Boje et al., 2020).

The implementation of BIM in the design subjects of architecture programs in Colombia has not occurred at the same speed as its implementation in the building industry. In this sense, the teaching and learning of design is not yet fully benefiting from the potential use of data, models and documents embedded in design. This would allow new paths to advance in the design process, as well as new routes of analysis and evaluation of the design in the life cycle of the project.

Information modeling connects the data that structures the design information and its application to the project as a synthesis of knowledge. The type and scope of the project, the context of the project, added to the knowledge and experience of the design team, allows defining the quantity and quality of input and output data that configure the flow of design information. Likewise, the design criteria are enriched by the quantity and quality of information that is applied to the solution of a problem in a certain context. In the design process, information processing is understood as all the actions of the designer for the formulation of the design problem and its solution (Montaño Bello & León Rojas, 2020). The BIM methodology is an ally for the management of information that affects the formulation of the problem and the search for the design solution. It advances iterations and optimizations from the conceptualization stage and efficiently organizes workflow, technical coordination, and design documentation (Montaño Bello & León Rojas, 2020).

The implementation of the BIM methodology in university teaching processes in architecture, in tune with STEAM-type educational models, University of Bologna and with theories Management contests such as Lean Construction or Integrated Project Delivery (Montaño Bello & León Rojas, 2020), mean an opportunity to strengthen architectural design competencies by incorporating them into the traditional space of the project workshop.

Since 2018, the UTADEO School of Architecture generated an action-research space in the classroom through the planning, development and continuity of the Architecture and BIM workshop. The research presented assumes as a hypothesis that the implementation of BIM methodology in the training process of future architects allows the integration of structured information as a condition for the entrance of formal and spatial production of the architecture.

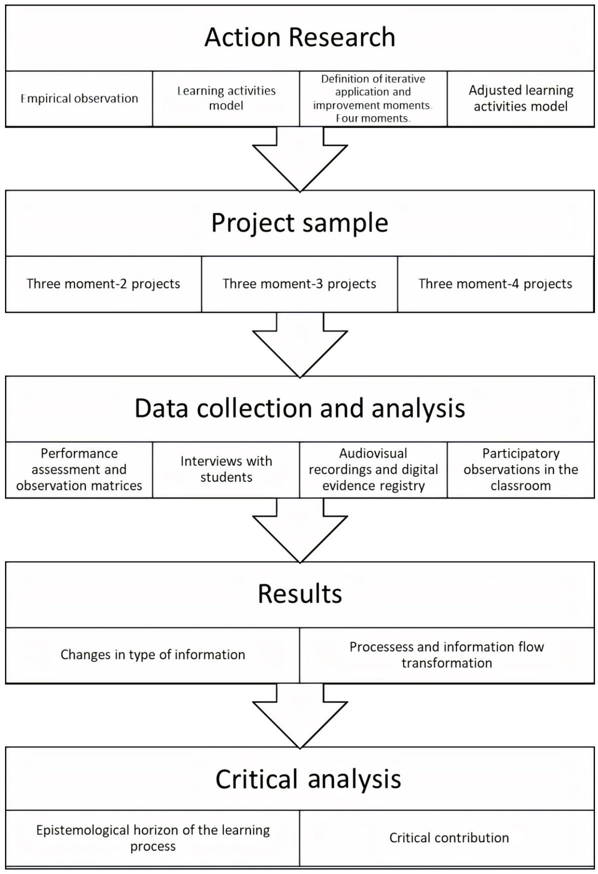

Figure 1. Methodology diagram

Source: Authors

At the same time, it strengthens a projective thinking based on the life cycle of the project and the development of high-performance architectural designs (Montaño Bello & León Rojas, 2020).

2. Methodology

Action Research (Frayling, 1993) is based on reflection in action (Latorre Beltrán, 2003). Its pedagogical research methodology starts from an empirical observation in the classroom that establishes connections between learning activities and learning outcomes. Subsequently, a hypothetical model of actions is built to structure a pedagogical planning and provide a causal explanation of the teaching and learning phenomena given in the classroom. Finally, the pedagogical planning model is subjected to multiple iterative cycles of improvement that affect practice and adjustments to the following planning model.

The applied action-research was developed in four moments: planning workshop in the first and second semesters 2019, the first semester 2020, the last feedback from this workshop and the planning of the second period 2020. The structure of the action-research is based on a design exercise proposed to the group of students, who simulate the work of an architectural agency that receives a commission declared and executed through a specific BIM Execution

Plan.

2.1. Project sample

The action-research worked on design processes developed by two workshops between 2019 and 2020 corresponding to stage two, three and four of the research. Each workshop was made up of 3 project subgroups, each with 7 members according to the specialties involved in the exercise, for a total of 9 projects evaluated in 18 months of work, as follows:

- Stage 1: Organization of the workshop teams.
- Stage 2: Team 01: Project Men's clothing store. Team 02: Cocoa Shop project. Team 03: Perfume Shop project
- Stage 3: Team 04: Watch Store project. Team 05: Cocoa Shop project. Team 06: Children's clothing store project.
- Stage 4: Team 07: Cocoa Shop project. Team 08: Cocoa Shop project. Team 09: Cocoa Shop project.

2.2. Data collection and analysis

For the Action Research (Till, 2008) process, documents, models and data obtained thanks to the following instruments were analyzed.

Performance assessment and observation matrices. Evaluation rubrics were used to establish criteria and scales for evaluating the learning evidences and their relationship with the learning objectives proposed by the workshop. The instrument allowed analyzing the performance of each team and each member in each of the moments proposed in the research design.

Interviews with students. Structured interviews were conducted with the students in each of the project committees. These were recorded and allowed their subsequent analysis. This instrument allowed us to analyze the relevance of the proposed activities as a basis for their subsequent adjustment.

Audiovisual recordings and digital evidence record. By time three and four, the quarantine derived from the Covid-19 pandemic, led to synchronous sessions with technological aids that were operated remotely. This condition allowed having a digital record of each session and the possibility of observing and analyzing the learning results in a digital repository.

Participatory observations in the classroom. During the process, notes and records were taken on the achievements obtained, as well as on the difficulties expressed by the students regarding the construction of their learning evidences, both individually and in groups. This instrument allowed the evaluation of the activities and their effects on the planning of the workshop.

2.3. Critical analysis

The results recorded in the following point three allow to formulate in point four, and from an epistemological point of view, a discussion of the architecture teaching model in Colombia. It is based on two critical contributions supported by the concepts "potency" and " asignifying" formulated by Deleuze (1981/2003), and "indexes" and "indices" a concepts worked by Van Lier (1996/2014) and Huyghe (2019). The critical contributions will link these concepts to two results of the Action Research developed in the classroom experience, with the purpose of demonstrating the changes brought about by the BIM methodology in the teaching of the project in architecture.

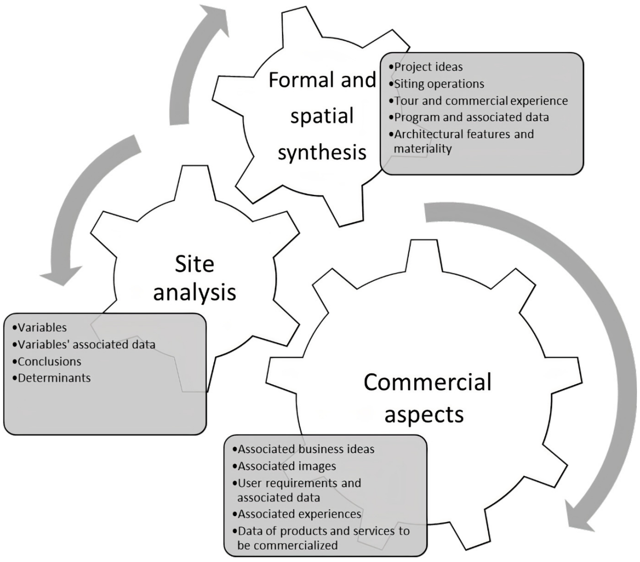

Figure 2. Conceptual map of the Kahau commercial project

Source: Architecture Workshop & BIM (2020)

3. Results

The exercise allowed us to identify findings in two important variables: 1. The change in the type of information that flows during the design process; and 2. The transformation of processes and flows of information. These changes are related to improvements in performance indicators and in learning outcomes for the traditional teaching-learning processes of architecture design.

3.1. Change in type of information that flows during the design process

In the initial stages of design, unstructured information (I) is usually constructed, that is, valuable data for the project thinking process such as sketches or analogous models. However, since they are not made through electronic means, they are not computable or interoperable. Even so, they are progressively integrated through documents and models that drive the projective thinking of designers to advance in the consolidation of more elaborate project hypotheses. Figure 2 shows examples of this unstructured information generated in the initial stages of the process.

In the development of the design, digital tools are incorporated and one can migrate to an increasingly structured information (II). Computable data and information that is organized for different purposes and uses in the project are produced, such as digital models, 2D drawings, digital images, digital documents of all kinds, etc. However, this information is usually not connected. This structured information generated early in the process involves architectural plans and renders.

With information modeling (III) it is sought that certain design data are structured and integrated into a 3D model for particular uses. For example, figure 3 shows different models of the same project that are used for the spatial analysis of the design, the structural analysis or the analysis of facilities. The structured information that is modeled allows it to be processed by the machines and used for multiple processes. Among these are the planning, simulation and testing of the solutions that are decisive to guarantee the quality of the design in the later stages of the life cycle of the draft.

The characteristics of the types of BIM models depend on different factors. The most important - which are also integrated with each other - are the type of project, the scope of its development by phases, and the dimensions that it integrates. These in turn define the BIM uses that the model will have and the level of development of the model, which is known as the LOD. This in turn is made up of levels of graphic advancement and development of integrated information. Figure 4 illustrates the relationship of these aspects in the definition of the information modeling developed in the exercise.

A final stage in the management of design and project information is the possibility of generating and using integrated data (IV), that is, interconnected and highly structured information. Such information is produced by multiple sources and managed in a common data environment that can be used in multiple projects and different platforms.

3.2. Process transformation and information flows

The transition from processes based on analogous media to processes based on digital media implies translating unstructured information into structured information for modeling and integration. The design process is thus fed with structured information that allows better decision-making from the early stages. The integration of data associated with the conditions of the site and its analysis, data that allow better technical analysis and 3D coordination which facilitate the estimation of costs and construction phases, or the construction scheduling are some examples of how the information-driven design can be optimized. Figure 5 shows a matrix with data integration, product of the modeling of existing conditions, and site analysis. It is useful for selecting between initial designs alternatives.

In the experimental exercise carried out, activities of the design process with different degrees of autonomy in the production of design information were identified: assisted activities in which the tasks are carried out manually by the student with the assistance of the computer, such as graphic modeling and incorporation of data into the model; automatic activities such as tasks performed by the machine after preliminary programming, for example construction simulation based on data from external programming; automated activities in which the tasks are executed by the machine, for example in processes of quantification of pro-

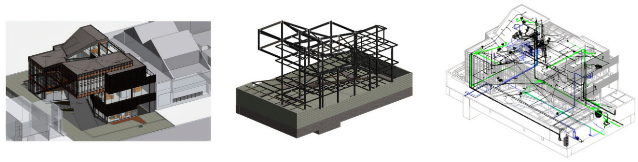

Figure 3. Information models of the Kahau commercial project: architectural, structural and technical installations

Source: Architecture Workshop & BIM (2020)

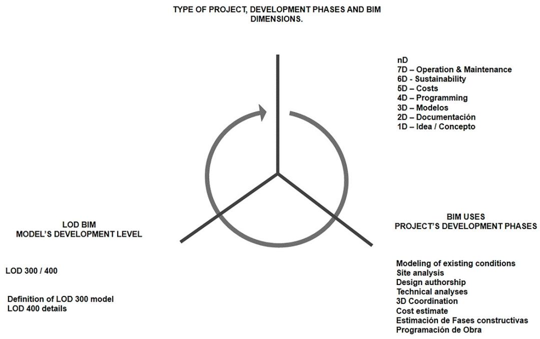

Figure 4. Aspects that define the types of information modeling in the design

Source: Authors

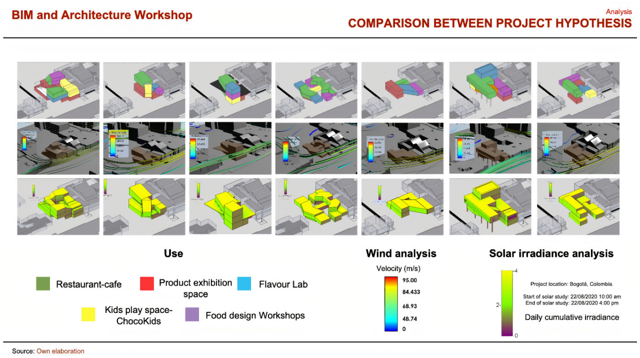

Figure 5. Analysis matrix for the selection of design alternatives for the Kahau commercial project

Source: Architecture Workshop and BIM (2020)

ject areas or of components and materials. In figure 6, a diagram is presented with the three types of activities identified in the design process.

The exercise allowed evidence of improvements in the skills for collaborative work thanks to a common data environment, the use of protocols, and the flow of structured information. The quality of the information produced accounts for the improvement in the design results, synchronized with reflections on the performance of the design in the project life cycle. A better performance of designs in multiple dimensions is also projected as a result of energy, structural and bioclimatic analyzes, among others. Finally, there are improvements in control from the design on cost and time constraints of the project, an aspect generally isolated in traditional design teaching processes.

3.3. Limits of the experience

The information generated through the exercise also shows limitations derived from the technological resources used in the workshop, in terms of the degrees of integration and autonomy in the generation of information. As information is structured and integrated to advance the development of design in architecture, the importance of knowledge as a basis for decision-making and as a fundamental resource for the synthesis of design is also understood. The project is thus understood as a synthesis of knowledge based on a complex interconnection of graphic and non-graphic information, in turn based on a large amount of integrated data. The design exercise takes place in a set time of 16 weeks that limits the number of design iterations. However, the results show an awareness of the importance of integrated information for the continuous improvement of solutions, both in the progress flows verified in the production of deliverables, as well as in the revision flows verified in the feedback of the process and in the partial results obtained.

4. Critical contributions

For a theoretical proposal to be accepted as a valid conceptual framework or as a predictor of reality, it must be adequately described, explained and comprehensively tested over time and under different operating models. In addition, for a conceptual framework to continue to reflect process innovations and to benefit from emerging opportunities from information integration, this process of description, explanation, and testing must be iterative (Succar & Poirier, 2020). In this sense, the description and explanation of the experience, in addition to allowing it to be improved by other researchers and peer-reviewed through open scrutiny, questions the relevance of current epistemological frameworks in the practices of teaching - learning in architecture.

This section is developed from the articulation between the results of the study and the concepts indicated, from which the two critical contributions arise. Thus, the first contribution entitled "Computable data and visualization" links a first result of the study, the type of information that flows during the design process, with the concepts of indexes and indices, in order to make evident how, depending on the type of information, the digital visualization of design processes exceeds the visualization possibilities of the classical perspective. The second critical contribution called "towards a new epistemological horizon" links a second result of the study - the transformation of processes and information flows - with the notion of power. The objective is to explain some modifications that the BIM methodology contributes to the teaching of architecture.

4.1. Computable data and visualization

The relationship between unstructured and structured information implies that analogous non-computable data are raw material that cannot be reduced to significant data

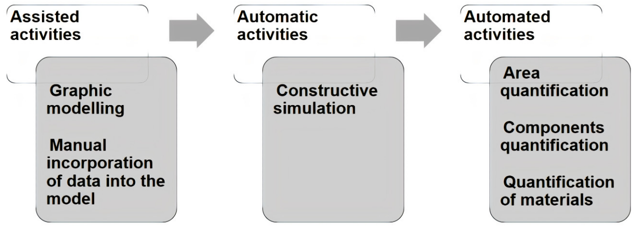

Figure 6. Some activities of the design process and associated degree of autonomy

Source: Authors

or information. However, in the digital interface where structured information enables the production of information models, some computable data act as raw material. These asignifying data behave as an event in tension with significant computable data, articulated to one purpose: the development of a high-performance project. However, asignifying computable data, without being articulated to a specific meaning, also affect the development processes of a high-performance project. Of these processes, the information visualization process is suitable for exploring the productive tension between data.

In the information visualization processes of the workshop, significant data (structured information) is recognized. They are signs of an established meaning. The student confronted with visualization processes recognizes the data as chained to the trajectory of a previous data. In this process in which the data is articulated according to a specific meaning of information visualization, for example, representing the spatial systems of a project, the parameters of the visualization processes do not necessarily vary in relation to the visualization parameters of the analogous supports governed by perspective. Now, in epistemological terms, within the framework of the parameters of the classical perspective inscribed in the processes of digital visualization, the asignifying computational data are perceived but not recognized, because they are not articulated to the parameters of the established visualization regime.

In the information modeling that integrates analytical data from the site in figure 4, the integrated data is indexed to the perspective; the information visualization is adapted to a form familiar to the student. This procedure where digital innovation of computer modeling is assisted by the past, the perspective, corresponds to the early adoption phase of the technology. Just as the way the first cars were made, when they did it in a way that intended to disguise that, in reality, it was something that had no precedent. Zuboff calls this the "horseless-carriage syndrome", the first cars were built with the appearance of carriages, like horse-drawn carriages, so that their novelty would go unnoticed (Zuboff, 2019). However, the indexing of the unfamiliar to the familiar does not exclude of the visualization field of computer modeling the asignifying data from the field of visualization of computer modeling. They are visualized as interconnected networks in three dimensions or as energy flows that trace the solar incidence on the volume in perspective. In the digital interface, the asignifying data affects the visualization of a space in perspective, which is made up of significant data.

Asignifying data are "indices" and significant data are "indexes". Indices are not signs, but rather the effects of a cause they physically signal either through 'monstration' – as when the imprint of a boar's paw shows this same paw – or 'demonstration', as when a disarrangement of furniture might reveal a thief's path through the house. Indices are non-intentional, non-conventional signs. Indexes indicate objects in the same way as the index finger might point to an object. Indexes are intentional and conventional but designate nothing by themselves (Maes, 2008).

An asignifying data is an indice that can be considered an act when referring to the domain of the real, while the significant data is an index or action that refers to reality (Van Lier, 1996/2014). Now, actions are also different from one another: one indirectly encompasses the act and indicates it; the other one encompasses it directly and expresses an increase of a potency (Deleuze, 1981/2003). The indicative "action" then differs from the action that increases the potency of computer model display images. These images would be indicative only if they represent the spatial coordinates in perspective of the analog images. However, the purpose of these images is not the constitution of a space in perspective. The perspective is no longer the line of convergence or the direction to which all the productive phases of the processes that make them possible must be articulated. In the images of a project developed with BIM methodology, the expression of the temporal and resource dimensions associated (4D and 5D) to the constructive modeling and life cycle of the projects are indices, asignifying data, acts, since these dimensions they have not been historically indexed in the image of architecture in perspective. Figure 5 shows the volume of a building in relation to energy intensity lines, which have no antecedent in the history of image, visualization and communication of architecture.

The temporal and resource dimensions, as well as the energy incidents, are indices of the real that acts in the reality of the architectural image, still subject to the perspective as reality of the architectural representation. The fact that project decisions are made in a participatory way with these indices means that such events act to increase the potency of the project. That the indices of the events are translated in terms of qualitative and quantitative information, speaks of the constant reconfiguration of the indexes from their exposure to the always-active indices. In this sense, the techniques of the present cannot be understood from the mental habits of the past; their capacities or potency increase due to the indices of the real that constantly reconfigure their interfaces and their codes.

Architecture should be thought not in terms of form but in terms of potency (Deleuze, 1981/2003). The development of projects with the BIM methodology increases the potency of the architecture since the data processing and the corresponding visualization processes allow the project space to be the effect of climate flow analysis and joint work where each one of the phases are productive. These cases are not explained from a line of convergence dependent on an idea or a vanishing point as in perspective, nor from a linear work organization where all the elements that affect their systems and interfaces, and that also make up their modeled and simulated images.

The development of parametric design projects with the BIM methodology and its visualization processes contradict the epistemological tradition, according to which the techniques, in this case a methodology in which various software participate, are finalized instruments of the designers. Understanding that a technique is unfinished implies that project thinking has been based on epistemological mistakes that, by idealizing ideas and articulations of meaning, have not retained all the data or asignifying actions that have constantly transformed the image of architecture. BIM facilitates a more productive participation to what architecture has always configured: the indices of the real.

To understand the permanent participation of data as indices of a specific reality, the epistemological and ontological paradigm of means and ends must be displaced. The purpose of architecture is always the physical construction of space. However, in its processes, there are indices of the real – solar radiation on surfaces, the fourth and fifth dimension in BIM–, which increase the action capacity of architecture. A projected space that results from the processes associated with computer modeling and a simultaneous work of conception / realization in which multiple actors participate in real time, is a more powerful space and, therefore, a more complete space with a degree of perfection (Deleuze, 1981/2003). The increase in the degree of perfection is not the purpose but the expression of a continuous increase of a potency. The modeled and simulated image allow exploring and presenting the possibilities of architecture, due to the incidence and participation of the real in its reality system. Contrary to the free simulation of the real, computer models are powerful thanks to the participation of the real.

4.2. Towards a new epistemological horizon

The teaching of architecture in Colombia is based on the French traditional model *Beaux Arts* and its conception-realization distinction. BIM information models question the project model executed according to an idea defined from the conception phase. The preeminence of the idea in this model of mental foundation corresponds to the transformation of architecture into arts liberated from its mechanics. This model still colonizes architecture teaching practices by being unconscious, not thought and, therefore, not discussed. In BIM, the conception is a phase of the project, the hierarchy of which is no greater than that of the construction or the operation of the building. The construction is no longer subordinate or separated from the conception, nor is it the execution of an idea. In fact, conception and construction begin to collaborate jointly with the other stages of the project process. BIM also implies a transformation in industrial management that links production with operations organized according to the same source (the idea), that is, according to a succession of tasks that are non-productive on their own (Huyghe, 1999/2015).

The classroom experience with the BIM methodology includes construction in project development. Unlike the idea that remains in its execution as it was conceived, thus indexing the products to the source, the construction is externalized in different elements. Products are detached (*de-indexed*) from a source, which can be architecture, but also network design or structural design. Additionally, BIM teamwork affects the economics of production and the *Beaux Arts* division of labor, since each phase of work affects the whole. If construction has to do more with production than execution, the principle of convergence of the classical production line is replaced by a mode of production whose non-convergent parts are dispersed and affect, each one simultaneously, the entire project cycle.

To conclude the analysis of the tension produced by the BIM methodology with respect to the *Beaux Arts* model, we turn to the notion of "modernity" (Huyghe, 1999/2015). Huyghe defines it by its difference with modernism, which does not do as before; it substantially modifies the heritage of the past. The economics of today's innovation society admits modernism: what was done before is done differently now; it excludes the classical in the method, but protects the classical at the level of appearances (Huyghe, 1999/2015). The same happens at the beginning of the 20th century with architecture: historicism, new materials and construction methods with an old look, suitable to be assimilated by classical taste. Here, rather than discovering inventions, they cover themselves with the past. The aesthetic, ethical and political problems that arise from such a trick - to accommodate the new to the classical taste, that is, to manipulate both the perception and the thinking of the users -, is a capital issue in terms of the strength of the *Beaux Arts* indexing systems on technological practices not adjusted to classical taste.

Modernity admits that the situation is not as before and registers the change by appropriating it. Modernity assumes the new techniques, as a *modification* of the current historical situation of the teaching of architecture, but without cutting off any relationship with the past or deceiving at the level of appearances (Huyghe, 1999/2015). This is the case at hand. As argued in the previous section, the visualization of the project development in BIM uses the classical perspective, but simultaneously, the images produced are unprecedented, and completely change the representative content of the project development processes.

5. Conclusion

Thanks to its relationship with technique, humanity can regularly redefine itself. Similarly, BIM redefines the teaching of architecture with the computer models in constant redefinition. A digital model of a building is not the building; it resembles the building, which is its objective system, but it is not its copy; it has different characteristics depending on what is intended to be understood with it. This allows digital models to improve and evolve, pressured by the facts, by establishing that the conventions of a given moment are not sufficiently compatible with the facts. The construction linked to architecture is not compatible with the epistemological model of yesteryear, which affects the academic idea of the architect.

Data management in the computer model of a building is an activity that cannot be understood from the classic epistemological paradigm of architecture, a paradigm where the architect is considered a genius whose conception work is the fruit of an idea. Before, the genius of the architect meant that his work was secret and solitary. On the contrary, the data management process in a computer model is redefined, without secrets, at each stage and in real time, thanks to the work of a community of professionals. In this sense, the architect works as a team with other professionals on projects that are developed progressively, according to the schedule, the operation, the life cycle of the project and all kinds of information necessary for the construction of the project.

The new epistemological horizon that is proposed lies in the design knowledge that is produced by the incidence of collaborative work, the technical contributions from different disciplines, and the conditions of possibility of technology related to the management of structured information from an early age of the process of design. This condition also implies a change in the design results from a new performance paradigm. These conditions, which are evidenced through the exercise of action research in the classroom, necessarily impact the pedagogy of the teaching-learning process and, specifically, the processes that occur in the space of the design workshop. The action-research exercise carried out shows the advantages of the implementation of the methodology from an early age of the design process and not only in its optimization phases.

The BIM methodology draws a new epistemological horizon by modifying the *Beaux Arts* model, the idea of an architect, and the architectural work and production. Architecture, in the end, affects all stages of the project's development. Such stages, being collaborative and creative, rather than undermining architecture, improve and enhance it.

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