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Integration of Agents in the Construction of a Single-Family House Through use of BIM Technology

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Abstract

The tools and work methodologies currently employed in the construction industry do not allow evolution to face up to market demands. There being, in addition, less time for project planning for which more detailed specifications are required and which strive for productive efficiency. In light of this, the development and application of production methods that favour multidisciplinary, integrated and collaborative work between the agents that compose the construction process is essential.
BIM, Building Information Modelling, technology arises as an answer to the need to integrate all the agents that participate in the process during the different phases of the work. In the present article, a comparative study is carried out between two methods of construction project planning for the real case of a single-family house. This is done by means of the traditional process using computer aided representation, CAD, and a hypothetical integrated process of project planning supported using BIM.
Thus, conclusions are extracted about the introduction of this technology, reflecting on the experience had. At the same time, recommendations are made for working with this methodology and possible future lines of action.

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Keywords: BIM; IPD; Integration; Construction

1. Introduction, construction in the residential industry

A starting point for this document are the statements that Nils made in Prouvé [1], who, already in the middle of the 20th century when all sectors had evolved industrially, postulated "It is true that those objects industrialised to a

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high level, that drive, fly or are stationary, are in a continual process of perfecting, their quality improves more each time and even the prices are ever more reasonable. The only industry where it doesn't work is in the construction industry".

This reality is a burden that the sector has had to bear until our times. Taking references from others, the construction sector, motivated by its peculiarities, in regards to quality and satisfaction quotas, despite having evolved, is still lagging far behind. This tendency has to change; evolution towards progress must be sought. The current recession that we are currently going through has to be taken advantage of to be able to introduce improvements. According to the judgement of Rico [2], the strategy to follow in the sector has to revolve around the following objectives:

- Increase and maintain relatively stable demand.
- Increase the level of industrialisation in the sector.
- Improve quality, this being understood as a wide concept that extends to all assets, services and activities in the sector.

The first of them does not depend so much on the participants in the sector, but rather on the financial situation that the market finds itself in, as well as existing finance and public grants that facilitate investment. This is something that is far from the presented line of investigation. However, the two subsequent objectives are directly concerned with the participants and they can intervene by means of changing the tasks of the sector. For this, the following are considered determining factors for evolution [3]:

- General technological progress, productivity, profitability and competition must be improved.
- Quality. The search for optimum satisfaction of the quality requirements.
- Work training, and work health and safety, that is to say, improve the working conditions on-site.

Based on this, the desired result is to intervene in the improvement of construction quality and of the work environment, concentrating on the integration of the agents and training. Application integration represents a strategic approach for unification of several systems, both at services and data level [4]. For this to work there must be changes in the work system, focused on the small scale. The construction sector and mainly in the interventions dedicated to residential architecture which is currently very fragmented, where production is carried out continuously. The flow of information is shared in a lineal way with complexities existing in the implication of each of the agents that become involved in the process [5].

In housing production, the most widely used work system is Design – Bid – Build, the DBB method, taken from the Anglo-Saxon translation (Figure 1). In order to work, this needs three main components which carry out the process, being integrated into this work through distorted communications due to their contractual relationships. The three groups of agents can be divided into the following:

- The first integral component is that which is made up of the owner, which in this type of intervention generally coincides with the figure of the developer.
- The second one is the design team which is composed of architects, building engineers and external consultants (designers, engineers…).
- The third component is made up of the people taking part in the actual construction, by the main contractor of the work and additional subcontractors which become part of the work, as well as additional entities.

In this widely-used method, relationships are formed following a lineal schematic. In the first phase, the design team and the owner draw up the mandatory projects in order to be able to request the permits as well as receive offers from different contractors, this being the moment when this party enters into the scene within the job, bidding for it, under commercial competition until they obtain the job and are able to start [6].

Fig. 1. Linear distribution of the traditional work system, DBB.

In residential single-family house-type proposals, as in this case study, as an average of this system, the owner has overall control of the work, conceptualising the project, managing the design team and the team made up of the contractors and subcontractors. Use of the DBB management model has advantages for the developer such as being able to take advantage of the impartiality of the design team who watches over the interests of the developer or have minimum dealings with the contractors that offer themselves up for the tender of the job in question, giving the owner the decision-making ability, helping him to establish a reasonable price for the project and completing the project, generally speaking, to acceptable quality levels.

However, this method presents a series of disadvantages; such as the increase in costs and delays in the project originating from errors made by the design team, with bigger risks existing also for the general contractor, possibly compromising the quality of the project with the aim of reducing costs, given that due to the delay in the introduction of this party to the project, he doesn't have the opportunity to introduce effective alternatives for controlled costs, where controversies could arise throughout the work between the design team and the construction team which is detrimental to the quality of the project. This would directly affect the owner [7].

It must be demanded of the construction industry that, given its economic influence, reach and the permanent manner of its effects on the physical environment, it is an efficient and quality-driven industry. Quality being defined as the level of adaptation of a work or of a unit of a work to the working demands that it has to satisfy [8]. Based on this, it must be indicated that research searching for improvements must be orientated towards an increase in this quality, both the product and of the place of work, which is implicitly associated with other tendencies such as training or the use of new information techniques.

Taking the work under the production centre concept, one can think of its similarity to an industrial factory. The construction of a building is a process of transformation of some inputs, such as the materials, machinery, energy, etc. (Figure 2). These generate a final product and this final product has to fulfil the ends for which it has been designed and planned. Each work is a subsystem of the basic system of the company as an organisation. It is an open system with a level of permeability adjusted to the available means and to those which have to be externalised or subcontracted. Also, the said system is conditioned by the final users, who are decisive in the modification of the system and its ultimate use.

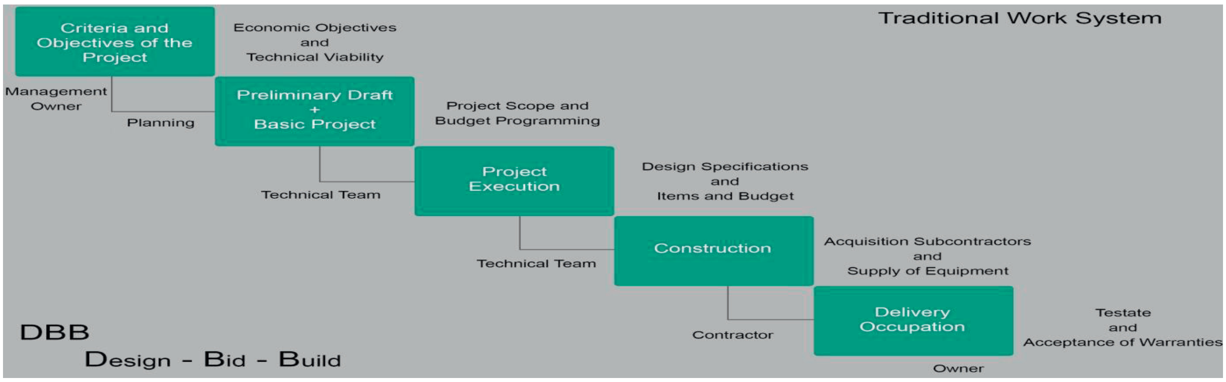

Fig. 2. Relationships of the traditional construction system.

It seems simple to approach the work as a production centre, but to be able to export the techniques and tools that industry in general uses to this sector, it must be taken into account that there are a series of distinguishing elements which set it apart from other industrial sectors, which have made its evolution difficult until now, thus making it very peculiar in many aspects [9]. Bearing this in mind, this research is written with an aim to improve, in the face of the proposed objectives of product quality and of the work place, as a step towards a solution for small scale jobs. The use of the collaborative design tool, BIM, is proposed as a system to be used that integrates the participants in the process of a single-family house build, extracting a comparative of its use against the described traditional system.

2. The Integrated Project Delivery system (IPD)

As an answer to the search for a method to develop integrated projects in construction, the American Institute of Architects (AIA), created a guide for the implementation of a system called "Integrated Project Delivery" [10], in which this method is explained as an approach that integrates people, systems, business structures and practices into a process that harnesses the talent and insights of all the participating agents to be able to reduce waste and optimise efficiency in all stages of design, fabrication and construction. It is based on a narrow collaboration between the owner, the design team and the general contractors, from the start of the design phases to the final delivery of the project. Collaboration in an integrated and productive way of all the members that make up the project is central to an IPD job.

The Integrated Project Delivery method is proposed to reduce waste in the construction industry, waste being defined as anything that does not generate value, through the collaboration of the participants in the project and the integration of new technologies. Borrowing a term from the manufacturing industry, following the steps established by Koskela and reinforced by the institute created by Ballard and Howell, a strong desire exists to convert building processes into something more "lean", by means of reducing the waste associated with low productivity, less than the desired level, and costly disputes between the participatory agents on the work [11].

The main nucleus of work is composed by a triad. Each member of the threesome is independently able, knowledgeable, but together they can have a greater impact. If one gets stuck, the others can help him. Making decisions as a team. Taking on risks together, with project objectives held above their own interests. The crux of IPD is based on bringing together the owners, design team and contractors from the start of the project so that they can share experiences and decisions are taken together in a collaborative way. IPD requires the owner, the technical team and the contractor to commit by means of a single contract that specifies their roles, rights, obligations and responsibilities. This nucleus will be chosen based on their experience, technical knowledge and ability to communicate and work in a collaborative environment. Other members will be added to the contract along the way and to the reach of the work depending on their level of responsibility and collaboration [12] (Figure 3).

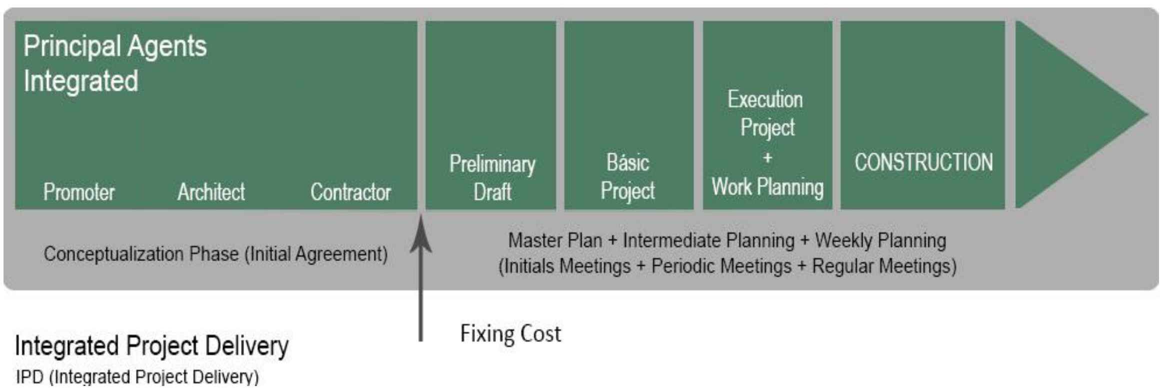

Fig. 3. Distribution of the integrated construction system, IPD.

Early communication between the three main project agents is established by using this methodology. Those agents are: the developer/owner (which in housing tends to be the same person in self-builds), the technical team (generally made up of architects and technical architects, in some cases also engineers), and the main contractor. Through this communication, the IPD proposal is generated, providing each one of them with the following benefits:

- Developer/*Owner*: it gives complete knowledge to the project in an early and open manner, which means there is no uncertainty in the result. It simplifies project communications, strengthening the understanding of everyone involved of the client's needs. This is something which improves the capacity of the team to control costs and administer the budget in an efficient way, with the objective of having a better chance at fulfilling the project objectives, including the timeline, costs for the life cycle, quality and sustainability.
- *Technical Team*: this process allows the design team to quickly take advantage of the contractors' experience, integrating them during the design phase, allowing them to request budget estimates for decisions to be made in this phase. In the project planning execution phase, it facilitates the design of constructive solutions, which improves the quality of these and the financial performance is increased through the adopted solutions. IPD design increases the effort in the initial design phase which results in a reduction of the final documentation, a better control of costs and budget management, an increase in the probability of fulfilling the project objectives and the timeline established and fulfilling the costs of the life cycle, quality and sustainability.
- *Main Contractor*: it allows for the contribution of his experience through providing technical knowledge. Through this, quality can be obtained in project planning and financial control during the execution phase of the work. The participation of the contractor during the design phase facilitates the opportunity to carry out a reliable work plan for execution. It allows complete knowledge of the proposed design, being able to anticipate and resolve problems related to the project, being able to visualise the construction sequence prior to starting the work, settling the control of costs which facilitates budgetary management which, once again, increases the possibilities of achieving the project objectives.

It is entirely based on collaborative construction which tries to create transparent and true relationships between the participants, looking after, above all, project targets rather than individual targets. The introduction of the IPD method can generate communications between participants with an equitable share of the risks and above all with a sharing of knowledge with the sole objective of increasing the value of the work to be done. The following matters must be established in order to set up the integrated team.

- As a starting point, the roles of the participants must be identified as soon as possible, making up all of the members who will be integrated towards this approach.
- The next step requires considering the interests of the project and the selection of agents in addition to the main ones (carpenters, quarrymen,…) defining, by mutual agreement, the value, objectives, interests and objectives of the participants.
- Finally, in a step before the definition of the project, the work structure best adapted to the IPD approach will be identified in a manner which is coherent to the limitations and with the participants reaching an agreement to define their functions and responsibilities.

Once the work team is prepared, the project flows from conceptualisation to execution and subsequent delivery. The decisions taken during the design phase are carried out quickly and with reliability of execution, thanks to the early integration of contractors and subcontractors to help define the project, making the small modifications, common in the construction of houses given the inexperience of the owners in these processes, more efficient and less costly. As shown in the image developed by [13], Figure 4, the effort invested in design is related to the changes that can happen in relation to the point in the project where they arise.

This improvement of the organisational system of construction processes requires a series of tools in order to be carried out, the existing contracts speak about two parties, one with a larger presence in the design phase, with the ability to model and simulate the project and the other of control, which allows continual monitoring of the work by means of the organisation of the meetings to be undertaken:

- BIM (Building Information Modelling), proposed as a tool from the design phase, provides the capacity to model and simulate the project with complete precision, serving as a project integrator between the design team, the owner and the contractors. This being a technology focused on the exchange of data and communication in real time within the construction sector [14].
- The Last Planner[TM] System, as a management and control tool during the execution phase. It is defined as a tool that generates a detailed calendar that covers each phase of the project. In collaboration-based planning, based on the programme in an inverse way. The transfers between the organisations of different specialities are identified in order to understand the best way to fulfil the benchmarks that are indicated in the master plan. Controlling by means of scheduled meetings what is going to be done in a certain period of time and what was done in the previous one, thus enabling the percentages of assignments completed (PPC, Percent Plan Complete) [15].

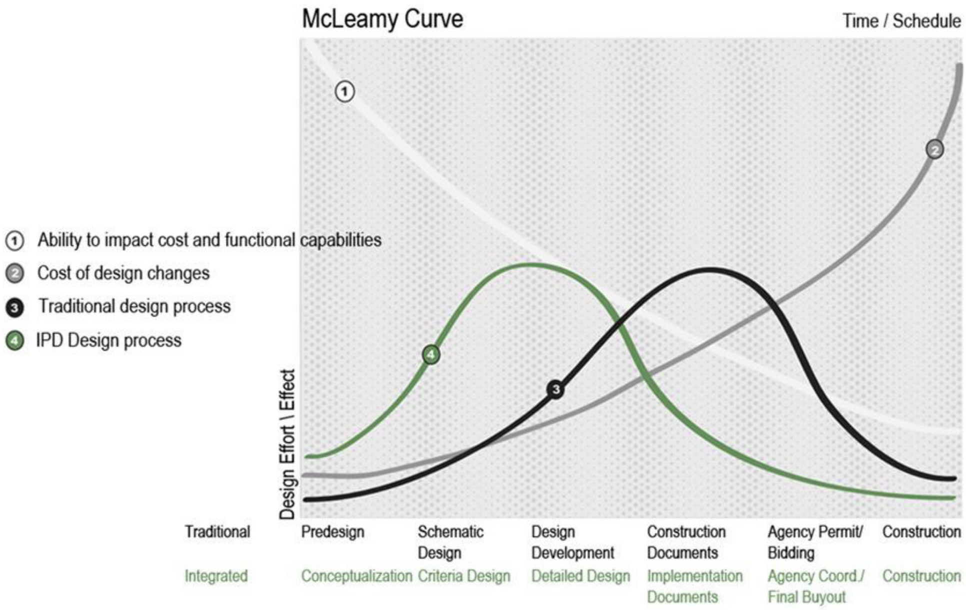

Fig. 4. McLeamy Curve.

In this investigation, we aim to analyse the introduction of the design-focused tool, BIM, in an intervention carried out via the traditional system of design, bid, build, for a single-family house under construction. The differences that are produced as a result of the elaboration of the project by means of 2D and 3D software representation system will be evaluated against the same project being developed using BIM modelling tools.

3. BIM (Building Information Modelling) technology

The representation tool BIM starts as a three-dimensional model tied to a database of project information, with this current support tool being the most powerful for IPD projects. This is because BIM integrates the design, fabrication, assembly instructions, logistics and project management into a database, also providing a platform for collaboration for all the IPD members. This is a tool, not a method; a tool that still is not frequently used in the sector; but it may end up enabling the efficient development, in very complicated projects, of projects that are easily understood by all the agents. The project team reaches an understanding regarding how the model will be developed, introduced and used. In order to carry out the introduction of this information modelling a series of usage protocols must be established in the conceptualization phase within the Integrated Project Delivery model by the different agents.

BIM is made up of a series of objects that are designed according to the essential characteristics that define them, that is to say, set parameters for them. This is done via an interface that conceptualises them and that aids their creation with a multitude of pre-established parameters in relation to the nature of the element that is aimed to be created. A wall, for instance, can be designed by the following values: number of layers, the thickness of each one of them, height, materials, length, etc… But it can also go beyond that including other types of non-dimensional parameters, like, for example, colour, material and weight, name, etc. The object that is modelled emerges much more complete and editable, allowing direct access to its characteristics. This way, representations are not modelled but rather the object itself is modelled, providing the largest amount of information.

The technique refers to the group of work methodologies and tools characterised by the use of information in a coordinated, coherent, computable and continuous way; using one or more compatible databases that contain all the information pertaining to the building that is to be designed, built or used. This information can be formal, but it can also refer to aspects like the materials used and their physical qualities, the uses of each space, the energy efficiency of its enclosures,… Ensuring the information is coordinated is essential so that the project can be successfully carried out by multiple users despite them being involved indifferent disciplines. The use of this technology allows for a reduction in the number of models and their automatic relation to one another. The objects are not representations but entities defined according to their characteristics that are later generated and shown through all kinds of specialised views, floors, sections, axonometries… This way, the designer no longer represents the architectural elements but designs them according to his specifications, following more or less flexible patterns, depending on the performance of the software and on his own abilities [16].

BIM, in regards to representation, is a tool where objects are drawn in 3D allowing for simple reading, through which spatial conflicts can be checked automatically. Given this capacity, both in design and in the levels of collaboration it presents, the changes derived from previous errors are highly reduced. To sum up, the work model is three-dimensional, which integrates different models (architecture, facilities, structure…) having the characteristic of being a 5D technology.

- 3D; in regards to the graphic representation, it completes the existing and consolidated three-dimensional work.
- 4D; being able to plan and control the work timetable from the information that is intrinsic to the design. It links dates with the properties of the objects, these dates being planned, it coordinates works, defines localisations and quantifies the units needed.
- 5D; by means of estimation and control of costs given the information provided by the design.

The use of BIM technology promotes an optimisation of the work carried out by different teams, advancing the project as the phases of the work advance, avoiding rework caused by modifications due to errors in the planning or in the understanding of the work.

4. Case study, a comparative look at the use of BIM software and the traditional method

The introduction of the IPD methodology, as with any change, even more so in a sector as traditional as the construction sector, has been very costly given the resistance to change and the untrustworthiness that has developed in the sector over time. In the presented case, its introduction was proposed but the developers did not deem it to be viable, given the personal effort that is implied in the elaboration of their own home, and given the climate of mistrust that floods the sector when faced with innovation. In light of this, this communication proposes the comparative study for the house that is currently being built as an evaluation of its use.

The house to be studied is in the construction phase, where the structure and enclosures have been carried out, as well as the interior divisions. To carry this out, in a traditional way, a basic execution project has been planned which has been used to obtain the obligatory town permits. Once the project has been planned and the permits have been obtained, as has been explained above, in a linear way, a series of companies have been allowed to bid for the construction, selecting, in this case, the one that most favours the interests of the client to carry the work out.

The tools that have been required in the drafting of the documents have been specific to each document in particular, such that a 2D representation has been displayed for the drawing of plans, using a CAD tool, in this case

"AutoCAD". Once this representation was displayed, it was modelled into 3D with the tool "Rhinoceros", for later rendering in "3D Studio." In regards to the justification of the structure and its calculations, "CypeCad" has been used, having to represent the model of the house once again. This is then represented once again for a fourth and final time for the justification of energy saving, using the national software "Lider". After using this entire mix of representational programmes, another final one has been used to extract the measurements of the materials used and the budget, in this case, "Arquímedes".

These software tools lead to errors in the transition from one to another. Working with different programmes, having to represent the same thing too many times, despite this being carried out by the same work team, given the dimension of the project, can lead to indiscernible variations because of the complexity of the elements; this will be translated into the work as a decrease in quality driven by the problems from this part of the design. The use of BIM technology tries to present, in just one representation, all the information needed to extract the data for the entire construction, trying not to drag errors between programmes and being able to check all the documentation after the normal variations that appear as the process progresses.

In this construction, as with any other, there are differences between what has been built and what was projected given the modifications and errors in the calculations during the planning of the project. Because of this, at the same time, the project has been planned using BIM technology, trying to extract data for the house and comparing the traditional method with the method established in IPD. For modelling in BIM technology of the house to be studied, the software "Revit Architecture" has been used, which has provided us with the virtualization of the house in a relatively simply way. In this data entry, by means of BIM, a wealth of problems have been detected that are invisible in the traditional representation, which should have avoided several of the resulting interruptions to the work, which has only led to an increase in errors and a tense work environment.

The use of BIM, in this case, has focused on using it as an internal tool for the technical team, with the aim of evaluating its reliability and use for future interventions. The current work system, given the lack of specialisation, is not ready for such a large change as the one that the IPD methodology presents and there is a lack of training in the use of new technologies. Due to which, a change from the design is proposed in the first moments, until an open collaboration can exist between agents using a common language. Once the BIM model of the house subject to this study has been completed, data can be extracted to analyse the two methodologies, on the one hand through quantitative aspects and on the other hand through qualitative aspects, which are more difficult to measure, describing the benefits that come from the use of the BIM model given its capabilities.

For the first of the analyses, the quantitative one, it is necessary to look for some characteristics of property that are quantifiable and comparable in absolute and relative terms to the traditional development and BIM development. A complete way of being able to analyse which method is most precise and more akin to reality, arises when comparing the material execution budgets which have been used in reality in the execution of the work, from both methods; the methodology which best estimates the reality, in principle, will be quantitatively better for development.

At this point, where the BIM model of the house subject to this study has already been completed and the execution of material budget has been generated for said model, we are already able to make a comparative analysis between BIM techniques for the creation of projects and the traditional methodology (Figure 5). The house, as stated previously, is not completely executed due to which the process continues producing data, but through analysing the situation up to where it has been executed, differences appear between the two measurements themselves and between the certifications of the work executed.

On the other hand, in addition to the easily quantifiable aspects like the accuracy in the needs for materials that has already been mentioned, the BIM methodology presents other particularities against the traditional techniques that are notable but which are not easy to quantify. That is to say, there are many qualitative aspects that must be highlighted to evaluate the use of BIM technology against traditional technology, in search of a better integration of the participants in developments:

- An increase in the visualisation of the project.
- Early detection of the interferences and conflicts between the different construction systems.
- Check and analysis for the control of a work with the information obtained about the project.
- A reduction in the volume of work documentation.

- A global improvement in the understanding of the project.
- An increase in productivity.
- An increase of the developer's confidence in the work teams, given better understanding of the process.
- Detailed organisation and reliability of the processes.

COMPARATIVE ABOUT FAMILY HOUSING CONSTRUCTION IN SANXENXO				
	Ud	Project Execution	Certificate	BIM (Revit)
CHAPTER 1 : Earthworks				
1. Land clearing and cleaning	m^2	165.5	165	
2. Excavation of open land (Basement)	m^3	289.95	321.3	
3. Excavation of open land (Foundation)	m^3	48	47.23	
CHAPTER 2: Foundation and Horizontal Sanitation Network				
4. Parking Floor	m^2	62.9	106.2	106.3
5. Basement Wall	m^3	29.25	27.28	31.44
6. Concrete Cleaning	m	69.5	60.82	62.09
7. Foundation of basement	m^3	22.74	29.73	27.68
8. Concrete ventilated foundation	m^2	62.9	106.2	106.3
19. Tied beams	m^3	3.9	3.24	3.89
CHAPTER 3 : Structure				
10. Steel Columns	Kg	191	206.36	207
11. Slabs incliner ladder	m^2	20.68	25.44	24.2
12. Concrete walls	m^3	47.72	39.35	41.79
13. Horizontal concrete slabs	m^2	261	264.45	272.14
14. Perimeter Beam	m^3	11.31	13.1	12.62
CHAPTER 4 : Facade				
15. Inside Sheet Facade	m^2	119.12	101.72	87.74
16. Cladding system	m^2	144.92	45	93.89
CHAPTER 5 : Partitions				
17. Interior Partitions	m^2	193.28	266.15	243.92

Fig. 5. Quantitative comparison of methods.

5. Conclusion

From this internal use of the BIM tool, conclusions can be extracted that incentivize its use or, on the other hand, diminish it. From the above, in a qualitative manner, more noticeable improvements are extracted, but the two existing realities also must be highlighted given the use of this software.

- On one hand, BIM works with some file sizes that are much larger than those of traditional CAD tools, requiring powerful equipment to make its use viable.
- On the other hand, the adaptation to this work format requires more effort by the design team, as they must be more thoughtful, visualising the project from the very start in three dimensions, requiring a high spatial vision capability.

Even with these disadvantages, which are, to a certain degree, hardly relevant, generally, in qualitative terms, the BIM methodology has been more advantageous. On the other hand, this can be concluded in a more objective manner comparing the budget data extracted from the two methods in relation to the construction reality.

In view of the results, clearly a better exactness appears between the measurements in the BIM model with what was really executed, a total average deviation of **50.2%** as against **27.33%**. In all of the areas, the relative, average deviation between the project and the executed reality is lower for the BIM model and only in 3 items it has had a greater deviation in respect to the traditional method. Figure 6 graphically and clearly shows this deviation. As a consequence, it can be concluded that the BIM methodology is much more precise than the traditional process of project planning.

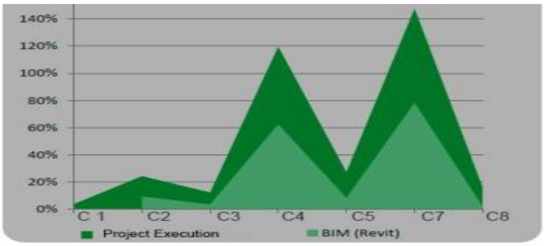

Fig. 6. Relative deviation per area.

From this experience, it is observed that with the change, an improvement in data reliability has been produced, being closer to reality than the projected data. Still, this change does not reflect the desired exactness given that the construction work is not very specialised and is greater still when introduced into small builds. For the BIM tool to also be successful in the construction process, it is believed to be essential that control tools are introduced, which audit the data produced, such as the Last Planner System, established within the Integrated Project Delivery methodology. Currently, qualitative leaps forward exactness can be observed given the modifications that have been carried from the project to the build. These variations, in traditional planning, are not reflected in all the documents given the complexity of the numerous tools that are used. The variations are not registered which then lead to more differences between the projected build and the certified build as the process progresses. By using the BIM tool, as shown in the images, this problem is resolved by being able to estimate, principally, the project data, introducing the modifications that could emerge into the model developed using this technology.

In a nearby future, following the analysis carried out which confirmed the positive implementation of the tools used in the integrated development of projects, we have to ensure its implementation in a progressive way, establishing guidelines that promote the formation of agents that are part of the construction process for their appropriate use. With this, we have to test additional tools that complement the studied, gradually introducing them as continuous improvement of a sector delayed industrially.

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