The Transformation of the Construction Industry

Martha Garcia-Saenz, MSCE.[1]
[1] Purdue University North Central, USA, mgarcia@pnc.edu

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Martha Garcia-Saenz, MSCE
mgarcia@pnc.edu, Purdue University North Central, USA

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I. INTRODUCTION

Although the construction industry has been one of the slowest to change to new technologies, in recent years the transformation has exceeded all expectations. For a long period of time the construction industry has been fragmented, linear, and full of delays; but after the advances in technology, today's professionals are forced into a situation of no return: either they update, or they will be absent from all work in the near future.

The hand drafting passed into history with the computer-aided design software. One of the advantages was the non-duplication by hand of the architectural drawings in order that the mechanical, electrical and structural engineers could incorporate their part into the set of drawings that would be part of the bid documents. When drawings were made by hand and at the time of the two-dimensional "2D" drawings sent via internet, the life of any project was fragmented in which, for a professional starting their own work, the previous should have finished theirs. It was important for the subsequent work in other disciplines that the architectural drawings were the most complete possible to avoid further changes in succeeding work.

Even though CAD software was considered a big advance, the fragmentation of the work continued and the project managers and the builders in charge of the construction had to study drawings very closely to find conflicts before it was too late during construction. However, many errors were frequently found and very often accompanied by requests from the contractor to extend the contract value and/or extensions in its duration.

The life span of the project for the architect began with the idea of the owner and ended with the architectural drawings. The same happens for each of the structural, mechanical, plumbing and electrical designs. They were all individual lives. The same happened for the constructor: the cycle began with studying the drawings for the BID, and finished with project delivery for occupancy to the owner. Any changes after this cycle was for the designer/contractor a new project with a new cycle.

The consequences of this fragmented engineering work is easy to visualize: a long time to complete the design before the bidding. Bids could not be opened until all designs were completed to avoid additional costs and extra time in the execution of the project.

The only way to shorten the time span between idea and occupancy of the project by the owner, was the "design and build" option. It allowed and allows better coordination between different professionals. The time span improved, but not enough. It has been impossible with "2D drawings" to eliminate changes during construction due to conflicts in the design from different disciplines. Accordingly [1], "changes in general are an integral part of the design process, which is interactive by nature because it involves the exploration and analysis of several alternatives to meet the budget." But many of the conflicts between different disciplines were difficult to detect before the start of construction since the designs were handled separately.

II. FUTURE ORGANIZATION

The evolution of computer aided systems has progressed to unexpected steps in the last twenty years. Two or three professionals may be working in parallel in different cities or countries. These professionals can communicate while working on the same set of drawings, communicating face to face through the computer screen if they wish to discuss technical aspects. In this sense, it is the same as was done before using the phone when commenting on drawings that had previously been received by mail, but now they can do it much faster since there is no waiting for the mail, or even e-mail. The two may have in front of them the same model that is in the same file saved in the cloud. With the use of internet communications, and a single file in the cloud, we can start speaking not only about concurrent engineering, but a broader concept called "corporate engineering" based on "integrated processes."

The project owner, or the leading institution, or the architect will be responsible for selecting or hiring consultants, contractors, administrators of the physical plant, and will hire the company or companies that provide the software and tools needed to feed the project's database that reside in the cloud (see Figure 1).

In this new collaborative organization, the designer (most likely the architect) returns to the functions that were lost over time. The contractor performs more functions in planning, estimating and scheduling of work, building the project (construction model) on a virtual model before even starting the purchase of materials.

Professionals and small companies that previously had no access to specialized software because they were very expensive, now do since the service will be via internet and the owner or his representative will be providing the software

required for design, estimating, scheduling, and communication to feed the project's database.

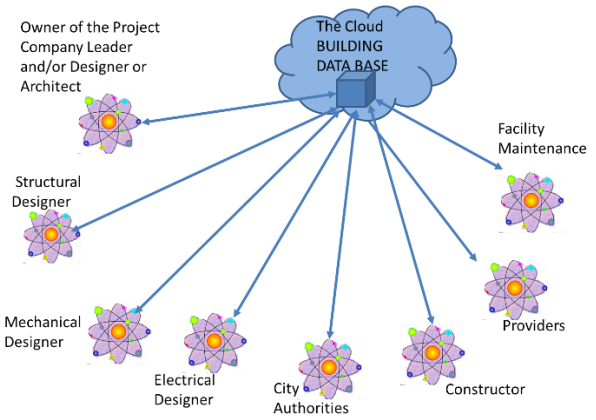

Figure 1. New organization focused on databases

It does not matter the location of the designers, as they will be working cooperatively through the internet and many of the meetings could be virtual.

I. BIM TECHNOLOGY

The BIM (Building Information Modeling) concept has been expanding to the extent of new possibilities, [2] defines BIM as "a database containing all the information needed for the design, construction and managing a project, including all the underlying knowledge, heuristics and contexts that control the design, construction, and decision making."

The BIM technology is the integration of different databases with the ability to perform dynamic processes. We can say that BIM is in grand part responsible for the current and future changes in project management. Another involved party is environmental engineering that has created the need to be more responsible for the planet and future generations. Therefore, we talk about green engineering, sustainable engineering designs with unconventional energy and sustainable designs that take into account the environment from the conception of a product to its final disposal. The adoption of BIM has been increasingly important for the construction industry, which has to face challenges to increase productivity, efficiency and quality while working towards sustainable development [3].

One of the radical changes for the lifecycle of a project was that it was residing in the professionals with many different short lives and now is a single project life that goes from the owner's idea, design, construction, occupancy, maintenance and final disposal after the structure is no longer in use and does not become a harm for the world. The life span of the project is no longer a set of short lives, thanks to the database that becomes like the brain of the project.

Having a model created with a database is like having a living body with a brain where all the information is registered. Some of the data that has been incorporated due to the ISO 14025 is the environmental product declaration (EPD), globally applicable and based on the analysis at the Lifecycle level that includes information about the environmental impacts associated with a product or service, such as the acquisition of raw materials, energy consumption and efficiency, content of materials and chemicals, emissions to the atmosphere, soil and waste water generation. Further information about the manufacturing company and certification of each product is provided by a third party [4].

The information provided through EPDs is used for LEED certification (Leadership in Energy and Environmental Design), which is a certification system for sustainable design by incorporating aspects of energy efficiency; use of alternative energy; improved indoor environmental quality; efficiency of water use; and selection of materials certified as sustainable. Currently there are four levels of certification: Gold, Silver, Platinum and LEED Certified [5].

What Changes Come With BIM?

By implementing BIM, coordination in the design changes radically, from sequential to concurrent, reducing drastically the design time. The work flow is different; therefore, a culture change is needed, but in the end, will be more beneficial and lower the expenses because the work is done in shorter time.

With the improvement of computers, servers and lately with "the cloud", the CAD we used in the previous decades, has changed dramatically. We went from a simple "2D" CAD to a "3D" CAD specialized for each of the disciplines: architecture, mechanical, civil etc. Servers gave the opportunity to work with several professionals in a single design simultaneously. Concurrent work that not only spread with CAD software, but the software for estimating and scheduling with a central database that additionally facilitates the work from the job site, or the main office, or from anywhere with internet access.

Models in 3D and BIM

With "3D modeling", a new philosophy in the design and construction came to the offices of engineers/architects. Most recall having played with LEGO blocks, making houses, castles, trucks, construction vehicles, etc., basically that's what is done today with ArchiCAD, Revit, Chief Architect, or any other software for "BIM Modeling." They have a basic software connected to a database that can be expanded with the needs of the project. Whenever there is a need for an object that is not in the database, there is access to other wider databases where one can get the item wanted. For example, if a project calls for a bathtub or a sink from X factory, simply access the database provided by the software vendor and from there take the item to add to the 3D model. Software manufacturers simply receive 3D drawings from the manufacturer and place them in folders classified for their customers to use.

Product sales have evolved greatly as a result of new technologies. Before product manufacturers and suppliers had to pay to see their products included in general catalogs that

went to those professionals who had subscriptions to those catalogs, or the manufacturer sent salesmen to visit design professionals providing catalogs so that they could offer them to their customers. Today, manufacturers promote their products through web pages, providing electronic catalogs for free, where each object is identified and stored in a database containing prices, features, finished dimensions and 3D drawings. Designers then take those objects as they need in block form and place them in their 3D models.

After the 3D model is created in Revit, for example, the software has cameras that display the model as we have been accustomed to in the traditional drawings, showing each of the floors, ceilings, walls, or any interior or exterior view as it is required in two or three dimensions. The software does the drawings for us, not line by line as we were accustomed to in CAD. Architects and engineers in the past were used to working independently in their own offices and exchanging drawings with engineers from other disciplines. In larger companies with various professionals and servers, multiple professionals could work simultaneously on the same project because the software allowed them to do so and have only one file at a central site called a server. To solve many of the problems of simultaneous work, software packages that act as auditors were developed. First to find inconsistencies through "Clash Detection," or errors, for example an air conditioning duct crossing a structural beam, or two pipes occupying the same space. Second, packages that can run simulations for energy analysis, analysis of flows in ventilation or air conditioning. Third and finally, packages that track changes that occur in the model to name just some of the applications on the market, since we will refer to other software packages later.

For example, time for designing a road now is drastically reduced by the ease of transfer of data not only between software packages but also the use of data collected through artificial satellites, known as GIS (Geographic Information System). The data collected by satellites is transferred to local coordinates facilitating the reproduction of the topography on the computer. With specialized software designing a road between two points, A and B, a line is drawn between those points and the software will produce a relevant, efficient design taking into account the minimum volumes to dig, the local codes and standards, and specifications supplied. This will substantially reduce production time, construction costs, and facilitate checking government agencies for compliance with established standards. Some software packages are so advanced they reproduce the new contours of the land, work scheduling (4D) and estimates (5D).

Models 4D, the Work schedule and BIM

The incorporation of BIM, the progress in computer programs and capacity, has created the opportunity to automate the schedule of work and generate the display of the sequence of construction, creating what is known as "4D" or visualization of the constructive process.

The drawings in "2D" required the engineer or builder with experience to visualize the project in three dimensions as well as the sequence of construction to proceed to meet the project's schedule. As a process that requires a lot of common sense, it was always important that a professional with experience in construction be creating the schedule.

To reach what is used today, generating activities and visualizing the sequence in the model, it has required more than twenty years of work from many initiatives around the world. The first step consisted of generating a list of activities; the second step consisted of displaying the work schedule; the third was to automatically connect the activities and the 3D view from the BIM model [6]. With the arrival of 3D CAD and establishing the relationship of the activities and BIM, models have been able to reach the simultaneous generation of activities in the model. Production rates are provided by the team or the person responsible for developing the schedule or from up to date productivity rates from databases.

Models 5D, Estimating, and BIM

"The project cost is possible due to the implementation of the parametric model that can be created with the help of BIM software" [7]. With three-dimensional models supported in databases, quantities and prices can be extracted in the form of spreadsheets or exported to specialized software in estimating to quantify the costs. What was mentioned so far is known as the technology of "5D" which is maturing to the point that some software are able now to have a very close estimate from the 3D model.

Most of the existing problems are related with the different types of estimates (Preliminary versus Final). Another problem is that the estimate is based on a single, external database, as well as the choices the design team make when shopping for the software package for a project. Yet another challenge when extracting data from the BIM model is that it has to be done by professionals with experience in estimating since the project could require temporary structures or special equipment during the construction process. "For now it appears that the construction estimate should be linked to 'clash detection' to detect the constructability of the sequence of the work to be close to reality" [8].

III. SIMULATIONS

Another change with BIM models is related to complex simulations. These can be done today thanks to new software packages that allow simulations of the physical behavior to analyze its efficiency in many aspects such as behavior; performance and energy of the structural; electrical; and mechanical, water and sewage systems; among others.

Resistance exists by some faculty or professionals of the old guard to make designs with three-dimensional models suggesting that students are not learning what they should due to the short time required between the development of design and drawing; but this is most likely because they do not know how to use the new tools that not only have the rules embedded

within the software, but that analyze through simulations how the new project involving building, road, water, sewer, power line etc., will behave over time. With simulations, one not only checks that it complies with codes, but can analyze the possible failures of a system over time.

For those people accustomed to using software packages for scheduling or hydro sanitary systems, it is very easy to understand what that simulation means. When assigning times to each activity represented by bars joined by some sort of sequence and pressing the button that represents the clock time, the program will calculate the duration of the project. If one changes the variables, such as duration of one or more activities and presses the clock button again, the software calculates the new time for the construction. What is done here is just a simulation, where the computer calculates the duration for different routes or "paths" for the total duration. Similarly, one can do other simulations, such as calculating air flows in air ducts in a building, or the flow rates and other parameters like energy in a pipeline or in a sewer system. So calculations are much easier and drawings are produced simultaneously giving the possibility of analyzing more variables that lead to a more efficient, more economical and more detailed system.

IV. 3D PRINTERS AND OTHER CONSTRUCTION EQUIPMENT

Artisanal models kept the construction industry completely asleep for centuries. The digital models created by architects and engineers today work in two ways: 1. Assembling parts with high precision in manufacturing facilities will be replacing some of the craftsmanship that we have been accustomed. Manufacturing parts that are assembled with precision and efficiency results in higher quality and allows sustainable construction with less waste that craft works. The construction time is substantially reduced and many of the assemblies can be performed by robots in assembly lines similarly to what happens with the automotive industry. 2. Already developed 3D printers in Europe, Asia and North America can build houses in situ with concrete and other materials that require a minimum of people. They have been building homes in actual size in particular (see Figure 2) in record time of one home per day and have been conducting trials with different materials and concrete with concrete reinforced with fiberglass reaching resistances between 12 500 and 14 000 psi.

3D printers are not only transforming the business of building houses but commercial and industrial buildings; majestic buildings from the past easily can be reproduced. We could not think to build today, as many of the magnificent projects built in the past. 3D printers with pumped concrete used as raw material can build the walls and have the ability to install additional elements such as windows, doors, beams, floors etc., which have previously been stored nearby. Each object is identified by bar codes.

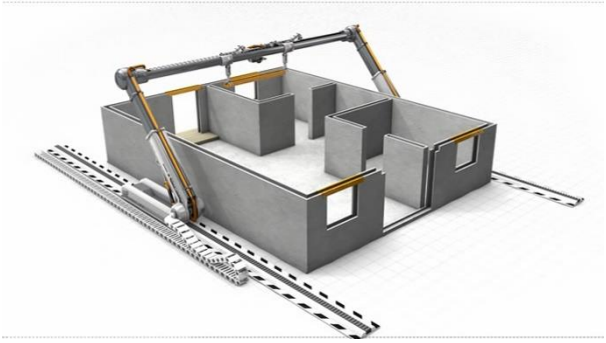

Figure 2. 3D Printer concrete taken from http://www.youtube.com/watch?v=QxqROe8tevo

The system of selecting materials by robot has been used for some time in railways where wooden beams and railing are first left in position for a robot that identifies the place where they are and saves the exact position where they will be placed by the contractor's machines on site. The software, after the final installation, will keep on its database the position in which each element was installed.

In manufacturing facilities, equipment with BIM software will help during the assembly of parts or systems by robots in production lines and workers in the field will install those pre-assembled parts into the project with the help of some robots too. Construction equipment is now in the process of being reinvented and can do activities during construction in different ways than was previously accustomed. For example, in highway construction where they used to build layer by layer, new equipment with less labor are performing those activities simultaneously with greater precision and efficiency, to mention only one.

V. WHAT OTHER CHANGES ARE COMING?

Of course the more one has, the more one wants; every time the computer does certain functions, new ideas come up and the desire is for the computer to do more. While that is natural, the problem is the increasing size of programs that require software to specialize in areas and to facilitate communications among themselves and with other packages using codes for communication. One of the main problems associated with this is the cost that can only be absorbed by large companies. Every year software vendors update their programs so that they can communicate with others and can perform new tasks, which in turn raises prices and becomes prohibitive for small companies that gradually became relegated.

Companies such as ArchiCAD, Autodesk (Revit & Navis), Sage (Timberline) and Oracle (Primavera) that produce software, have begun to provide services through the cloud. This means that software services can now be purchased as an internet service with many more advantages. The cloud helps companies to work smarter and more economically thus saving costs and time; becoming more flexible; agile and competent than before. Moving to the cloud means that companies are

more focused on the job without worrying about the technology that requires having technicians and systems engineers in each company to keep up with the internal network and installing software updates, which can be very expensive. Now small contractors may access the same packages that powerful companies use and allows them to more easily compete in the globalized world without large investments in software, hardware and technical personnel for maintenance.

According to [9], "It is expected that changes in the construction industry are presented along two complementary and orthogonal axes: Design and Construction/Assembly and Operations. They are complementary and require higher levels of engineering and design expertise to each project." This means that you have to give major changes both in manufacturing construction and onsite performance assemblies of parts. To make this possible, construction workers will be in front of computer guided robots and 3D printers in the factory or on site, making the assembly of the parts.

The most efficient manufacturing and assembly companies will be sending prefabricated parts for houses and buildings anywhere in the world. This may seem a little impossible, but to see that it can be done, one must know what has happened to the steel industry and the installation of water and sewerage pipes with the technique of micro-tunnels. The production of steel sheet used to have large numbers of workers around the production line that could withstand high temperatures (almost inhumane). Today, in the same production lines, they are working in a cabin with air conditioning in front of a computer with multiple screens analyzing the data through graphs. The data is sent through strategically located sensors along the production line and workers can with a few buttons send specific signals to the mechanical parts for acceleration, deceleration or water addition to get results within the specified limits. Something similar happens in installing pipes for aqueduct and sewer systems where workers are sitting comfortably in cockpits in front of a computer that graphically displays the data in numerical and graphical form, sending signals to the head of the micro-tunnel boring machine.

VI. DESIGN APROVAL AND CONSTRUCTION LICENSE

For the approval of the design by the owner and/or project management officers, they can be shown virtually the project using Google Glasses or the feature provided by the software to walk virtually over this and to experience enlightenment view spaces; even behind walls they may see the parts that are usually hidden such as pipes, air conditioning ducts, equipment etc. They may even experience the feeling of being in the middle of a garden or the natural lighting they will have throughout the year.

The employees of the government body responsible for the design approval may be granted construction permits easier than before since they can make virtual tours minimizing the time required to study the drawings.

Field's Office

Not all work meetings must be performed in the field office; some can be done online if the physical presence of the team members is not required. Of course, some assigned meetings will be at the project site. In the near future, the engineers will be able to use helmets with voice recognition systems for transmission of orders. In addition to that, equipment, materials and personal protective helmets can have embedded location systems. The tools will also be identified and assigned to individuals by a central command and all site personnel know what to do and where to go to work and even pick up and drop tools.

The project office no longer requires paper. Workers if not already doing this today, will have to learn to use tablets and manipulate 3D models or 2D. Through tablets, after identifying themselves, workers will receive instructions with tasks for each day to perform and the respective area where assignments are due. By the end of the day, each worker will register their progress. The software will then send feedback to the database and create a progress report that will be followed and approved by the supervisor.

VII. MAINTENANCE AND OPERATION

Thanks to the standards of data transfer, the model and data generated during the design and construction of a project will be available to whoever is in charge of the maintenance and operation of the physical plant and the administrator will know in advance which equipment or parts require replacement prior to any failure. This means that the administrator of the building or facility, in preparation of the budget for the next year, will know what equipment or parts are reaching the end of its lifespan. Additionally, the software packages used for maintenance and operation can also work with Google Glasses in the three-dimensional model to find, for example, the best way to access a specific point for repair or replacement of a part or a pipe.

Sensors embedded in the building will permit one to know how each part is working and responding to the specific conditions of occupation, climate, availability of energy, and maintenance requirements. Mechanical components with sensors could report to the proper parties that a part is about to fail or a unit is operating outside the design parameters.

VII. CONCLUSIONS:

With the current changes and its implementation, it is expected that there will be a higher speed and efficiency in the execution of designs and constructive drawings. Scheduling and estimating will be more exact since quantity take offs and cost expenses are done by the software in updated data bases. The implementation of new technologies will made improvements in the quality of construction, lowering risks. Carrying out of projects with high levels of complexity will be possible thanks to new technologies that are paving the road for product innovation and increases in customer satisfaction.

The world of architecture, engineering and construction is becoming less focused on the construction drawings and switching to a world focused on databases that share information through the cloud, avoiding duplication of information and facilitating the exchange and collaboration between different professionals and contractors, making the work easier and more precise. The new models are so detailed and in such high-resolution digital representations, almost life-like, that they require professionals with more knowledge of database software.

Work on schedules will improve since conflicts between designs from different disciplines can be avoided due to early detection and can happen prior to the physical construction. All will be possible thanks to integrated or concurrent design processes. With the change of culture to a world centered on shared databases, a new philosophy of exchanging data will be required and old professionals will need to learn how to do things and forget their old habits.

Companies that excel in the future will be those that have human and technical teams capable of designing efficient projects and/or those that can make precise constructions based on assemblies of parts that have been manufactured with green or sustainable materials and will be a common practice to include the disposal of the building when it reaches the end of its life cycle.

One of the key changes to reach the next level of efficiency in construction is that designers should use new tools to produce construction drawings with a higher degree of accuracy than the usual detail. An efficient design will be the one in which the construction drawings come directly from the 3D model. For this to be possible, designers must create a model with great detail.

Simulations of the construction process will allow one to schedule the arrival of materials and equipment to the worksite just in time when it is needed to be installed or used.

Not only the design has changed, the construction process has also been changing with the emergence of 3D printers that not only changed the design with new shapes and styles, but also allowed the entry of new construction materials substituting completely handcrafted materials with a more sophisticated computer-guided, pre-manufactured part.

Finally, companies that succeed will be those that develop more efficient projects. Efficiency is the measure of the future, both for businesses and projects. The Building SMART alliance [10] was created to lead the technical, political and financial support for the use of advanced digital technology in the real estate industry, from conception, design and construction through operations and management. In addition to advanced designs, you can collect and calculate the energy savings to be gained during the operation of the building with lighting systems, solar cells or heating and air conditioning.

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