1st Workshop on Process Technology and Constructive Systems
TECSIC – 2017
03 and 04 August 2017

THE IMPORTANCE OF INFORMATION TECHNOLOGIES IN THE DEFINITION OF NEW CONSTRUCTION SYSTEMS

FAIRBANKS, José Luis (1); CORRÊA, Fabiano (2)

(**1**) Master in Innovation in Civil Engineering, Polytechnic School of the University of São Paulo, fairbanks@usp.br; (**2**) Polytechnic School of the University of São Paulo, fabiano.correa@usp.br

Abstract: *Studies on the world market point out that there is a renewed interest in the use of prefabrication and the development of modular designs arising from the broad and growing adoption of Building Information Modeling (BIM), given its inherent synergy with building processes/systems. The term BIM is used in technical and scientific literature as technological innovation (computational tool). Moreover, it is referred to as a process in which a building is designed, planned and virtually built, with the support of a set of software. Furthermore, the term Virtual Design and Construction (VDC) appears in these same media as a synonymous of BIM with the addition of being a more spread concept, involving the digital modeling of the product, the production processes and the organization of these underpinning activities. Part of this ambiguity lies in the fact that, for information to be produced along these phases in a coordinated and integrated way, it is essential that there are very well-designed processes. Although the way construction and design offices implement BIM / VDC is not unique, it is believed that these information technologies will play an important role at new constructive systems. These systems will emerge as the adoption of the current industrialized processes, and the manufacturing industries are increasingly dependent on the Information aspect (represented by the computer aided Design - CAD, by the manufacturing – CAM, and by the Engineering - CAE). This article, which was developed as a preliminary study on the subject of a professional master's program, will discuss a possible extension of the understanding of constructive systems with the inclusion of the attribute of information technology (BIM / VDC). The method used for this purpose was a case study on of a steel-frame construction system.*

Keywords: *BIM, Construction System, Virtual Design and Construction.*

Knowledge area: *Process Technology and Constructive Systems - Production Processes - University of Sao Paulo.*

1. INTRODUCTION

Historically, the Architecture, Engineering, Construction, and Operation (AECO) sector deals with issues related to their productivity. Both problems are faces of the same coin: the low Productivity causes an increase in costs, which, in turn, feeds back to low productivity through the disincentive in investing in solutions. According to SABBATINI (1989), the project companies and builders work at a marginal profit that does not allow them to do anything but to survive in the market.

According to FERRO et al. (2010) techniques, methods and constructive processes have developed in an environment of general savoir-faire, in the practice of medieval potters, without any design, making the construction in a 1:1 scale directly on site. The project was developed at the same time as its application in the responsibility for construction, based on the empiricism of their own experiences, and through family learning. This was also the case in other areas of knowledge.

However, this apparent paradigm has been solved in other areas but has never been, until the present moment, in the AECO. Several approaches at different times (and by using different technologies), were tested by the sector and obtained somewhat successes. However, the productivity problem is recurrent. As described by SABBATINI (1989, p. 58), "It does not seem, for a vast majority of people, that a new way to build must appropriate a high "quantum" of technology, to solve a problem, rather than being only implementing another magic idea."

It seems to us that the inequality below (that does operate in other areas of the industry), still does not apply in the AECO:

Q(uality) x S(cope) > C(ost) x T(ime)

That is, the increase in Quality and Scope are desirable aspects, while the increase in Cost and Time, however, are undesirable elements (KIERAN and TIMBERLAKE, 2004). Instead, the inequality above takes the form of equality in the AECO, where Quality x Scope = Cost x Time. This results in inefficiency when compared to other industrial sectors. Thus, although the of numerous Constructive Systems throughout history, the AECO has so far been faced with the problem of productivity, which has always been the driving force behind technological change.

The speed of design and construction of the Empire State Building in New York in the years 1930-31 has never been broken by any enterprise (SACKS and PARTOUCHE, 2010). By analyzing documents of the time, SACKS and PARTOUCHE (2010) show that the collaborative design team represented an important innovation role, implying the low variation of design, continuous small packs of information flow, and a short time-cycle to deal with errors were the spot of that project. This is an iconic case for the understanding that the attributes of a constructive system - in this case, Lean Construction practices (even if it was not known as such at that time) - can boost performance.

A constructive system is, by definition adopted in this work, "a constructive process of high levels of industrialization and organization, consisting of a set of inter-related elements fully integrated by the process" (SABBATINI, 1989). This definition is based on three attributes: "a production technology (components and elements); a product design (the building) and a production organization "(WARSZAWSKI, 1977 apud SABBATINI, 1989). There is, therefore, no mention of the need and the importance of the so-called Information Technologies (IT). However, it is understood that the increase in complexity in the design and construction of modern buildings is only part of the explanation of the fact that the construction speed record of the Empire State Building has not been surpassed until today. The main reason for that may be for the low IT embedded rate in AECO the production.

Marketing studies around the world point out that there is a renewable interest in the use of prefabricated products and the development of modular projects arising from the increasing adoption of Construction Information Modeling (BIM) (McGRAW-HILL CONSTRUCTION, 2011). The prefab and modularization in the AECO to deal with the low productivity is not new. The use of IT such as BIM creates synergy with the industrialized processes, which points to the importance of IT.

The term BIM is used in the technical and in the scientific literature as much as a technological innovation (computational tool) as a way of how a building is designed, planned and constructed virtually, with the support of a set of applications. Also, the term Virtual Design and Construction (VDC) appears in these the same means as a synonym of BIM or as a broader process, involving the digital modeling of the product, the processes, and the organization altogether, more than only the product modeling. Part of this duality of the different visions of what is the BIM (a computational aid tool or a process) lies in the fact that, for information to be produced along the whole life cycle of the building in a coordinated and integrated way, it is essential to exist very well-designed processes. These processes may eventually change the way of how a corporation produce the building.

Although builders and design offices deploy of BIM / VDC is not unique, it is well understood that the Information Technologies will be important for future constructive systems once there is an increasing dependency on the information aspect (CARR, 2003). Adding to this is the fact that it is believed that the solution to productivity problems, delay in delivery of the works and overflow in the budgets, it is through the industrialization and the greater use of prefabricated, it is proposed to discuss, in a new perspective, what would become a constructive system in the current context.

This article, which was developed as a preliminary study within a master's program, will discuss a possible extension of the constructive systems definition, by including the attribute of Information Technology. The method employed was a steel-frame construction system case study for the usage in large-scale prefabrication of houses and building's automated design in Japan.

2. INFORMATION TECHNOLOGY

It is necessary to consider new possibilities for improving the AECO's production process with the objective of to make it more efficient and to bring it closer to the concepts of industrialization, like in the Automotive, and Aerospatiale, and Shipbuilding industries (GANN, 1996). The CAD technological development has led to the improvement of ways and means in the AECO (KIERAN, TIMBERLAKE, 2004; KUNZ, FISCHER, 2012). Thanks to the hardware accessibility as well as the development of new tools, CAD and BIM have evolved to a new level in the last 40 years. (EASTMAN et al., 2008).

Computer aid to design (CAD), manufacturing (CAM) and Engineering (CAE) systems began to surge in the early 1960s, transforming other industry fields by changing the internal processes. We can cite as an example, the more significant interaction between design and manufacturing thank the CAD / CAM integration leading to a considerable reduction of the time-to-market.

Contrary to widespread belief, the development of BIM was not a natural evolution of CAD systems. Already in 1970, Charles Eastman was already concerned with creating a system integrating conceptual design to an information database. Eastman though created the BDS (Building Description System), the first pre-BIM software, developed only for scientific purposes. In the BIM timeline, so many other products and languages were developed relating CAD design to a database, until the creation of the first BIM software (ArchiCAD in 1984) for personal computers (BERGIN, 2012).

However, the technological evolution of what has come to be universally called as BIM was a very particular issue. The effort was focused on information sharing since the fragmentation in AECO is too large. Also, there was an effort in developing collaborative work between professionals of different disciplines (IKEDA et al. 1996). These efforts eventually converged to parallel development of BIM such as the object-oriented modeling, which introduced components with a very well-defined semantics (one can create a "wall " object in a model, instead of only representing a geometric form related to a wall, as it is in CAD). However, several after nomenclatures appeared in the period, among them VDC, and Computer Integrated Construction (CIC), that today are recognized as been different concepts.

EASTMAN et al. (2014) define BIM "**as a modeling technology and an associated set of processes to produce, communicate and analyze construction models.**" However, Campbell (2006 apud EASTMAN et al., 2014, p. 13) portrays BIM only as a new computational tool. As emphasized above, some computational tools provide (and even demand), changes in workflows, which ultimately promote innovative potential in the design and construction performance.

With the use of BIM, a new form of contracting is favored, IPD (Integrated Project Delivery), where Engineering and Construction are carried out by the same company and may be previously established as a partnership which divides the risks and profits of a widely planned venture. Besides, everyone involved is encouraged to collaborate early in decision-making and conflict resolution planning. Through interoperability it is possible to integrate different software while maintaining the information integrity, speeding up, for example, the digital manufacturing of prefabricated components.

The technological innovations promoted by the ITs pervade the simple representation or digital modeling of the Product (the building), reaching the Organization and the production Processes (POP). Thus, the VDC also appears, which has been a term preferably used by professionals who deal directly with this technology in the construction (KHANZODE et al., 2006). KUNZ defines VDC as: " **the use of the integrated multidisciplinary project, construction, and organizational performance to support public business' objectives.** " It is important to note that all the essential attributes of a system constructs are eventually represented or modeled in the virtual environment of an information system, and the from this integration, the potential for innovation emerges.

In Japan, where the processes of automation and robotization have advanced considerably within the AECO, the concept of CIC was established from the CIM (Computer Integrated Manufacturing) from the automotive industry. Unlike the VDC, the CIC is extensively used in pre-fabrication of building subsystems parts. In the buildings automated construction, these components are suspended and installed in loco by the automatic system of transport, positioning, and assembly on site (YAMAZAKI, 2013). In VDC, no matter how it models the production process, these concepts are not yet adopted, because conventional production is, in general, manual. In order to enable automation, CIC provides a centralized shared database. (MIYATAKE, 1992).

A hierarchy between BIM, VDC and CIC concepts can be seen, where BIM deals only with the product, VDC increase some advances towards processes, and CIC is a fully automated construction system. In fact, there is a migration to integration with manufacturing processes, from BIM to VDC, and an assembly scenario at the CIC site (or off-site production) where the production system is automated, eventually with the use of robots, and where the computational system controls the machine or robot operating.

3. CASE STUDY

Our case study was led by the success (for more than 40 years), of Japanese large-scale housing prefabrication (LINNER and BOCK, 2012), added to the advance to an Automated Construction employing robots at the office buildings construction site, and the tight relationship of Japanese companies with the IT employment to support the hypothesis presented herein. In the single-family homes residential sector in Japan, there is successful industrialization of custom housing. Some socio-economic and cultural factors have contributed to creating a culture and a strong market for single-residential housing. The Japanese are culturally attached to the land but do not consider construction the same way; therefore, much of the renovation is used by demolition and rebuilding on the same lot with an intensity that ended up driving the residential market to renew itself every 20 or 30 years (JOHNSON, 2007).

Some innovations were decisive for the success of Japanese companies. For instance, the M1 modular prefabricated houses, developed in 1968 by Dr. Kazuhiko Ohno and soon adopted by the Sekisui Heim company, which started producing it on a large scale. Secondly Toyota Production System (TPS), with the proposal of the Just-In-Time (JIT) and the subsequent reorganization of the production chain. Thirdly the use of IT-based systems (in particular, HAPPS, from Sekisui Heim) to enable a high degree of personalization in prefabricated houses production, and finally the integration of the client within the companies' computational systems.

First, we will present the development of the CAD-BIM system of Sekisui House, HAPPS (ERP-BIM) system that enables efficiency in the Sekisui Heim custom home business model, and, finally, the SMART system for Automated Construction, from Shimizu Corporation.

3.1 BIM at Sekisui House

In Japan, prefabricated housing construction industry is dominated by large corporations that came from other sectors such as Mitsubishi, Toyota, Daiwa, Sekisui Chemicals, among others. Sekisui Chemical gave rise to two companies in the sector of prefabrication of houses: Sekisui House and Sekisui Heim. Currently, Sekisui House has become an independent company.

The post-war country reconstruction and the Korean War generated a surplus steel production, which led to the creation of subsidiaries for the construction of prefabricated houses using the steel-frame constructive system. This tradition of industrial production has evolved into mass customization so that the homes have appearances and functionalities that are almost entirely molded to the taste and customer's needs. The first constructive systems for prefabrication houses initially used the wood frame as raw material for structural purposes.

The more quality and added value home came by the production of highly customizable units, which added ingredients of complexity to the industry. Companies such as Sekisui Heim / House have CAD-CAE-CAM systems, developed their own standardization (modular design) and labeling of parts, blocks and construction subsystems in order to allow the most customized production, by the standardization of parts and building blocks. In this way, the various combination of parts and blocks yet in the design phase, will origin production orders for such parts which are further assembled in blocks within the factory, to be transported and assembled at the site (FURUSE and KATANO, 2006).

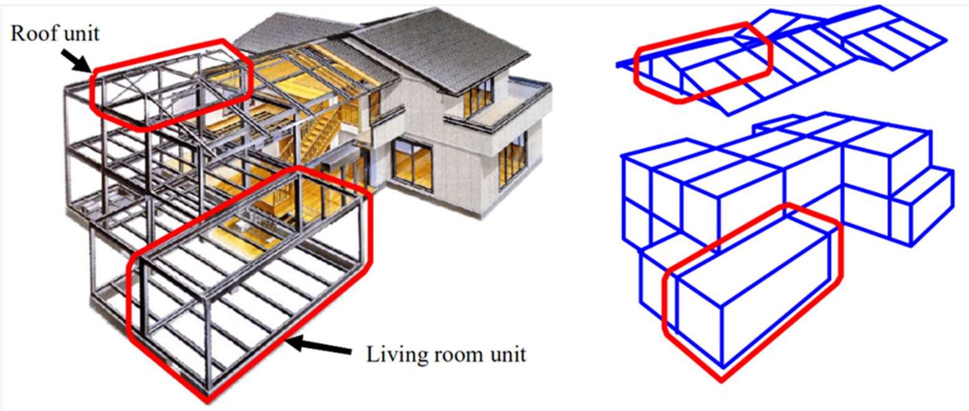
The CAD system developed by Sekisui House has a parallel to the BIM history, but much older. We can identify the original 2D system as early as 1972 (AUDESEI I) which further evolved into AUDESEI III (1979) until reaching the first fully 3D model in 1993. At that time, the system counted already on parametric features such as automatic specifications, up to 8 external views in perspective and a cost-estimate module that extracted data directly from the 3D model. In 1998 was created the first BIM software in Sekisui, the SIDECS. Today the company uses the SIDECS version 2010 system, comparable to other BIM market systems such as Autodesk's Revit or Graphisoft's ArchiCAD. A comparative study of Sekisui (AMEMIYA, 2013) shows that regarding worked hours, their system is even more efficient than Revit. Its principal advantage, however, is the integration to the HAPPS system which can integrate design and production (CAD to the CAM), performing several other analyzes available in other the BIM systems as the mass study, energy analysis as well as built for operation and maintenance. Furthermore, future expansion is considered and can be chosen at the very initial contract between the client and Sekisui House.

3.2 The Sekisui Heim HAPPS System

Sekisui Heim sells houses made up of three-dimensional modules, called "Units," which are prefabricated as ordered by customer wishes and assembled in the construction site. Each unit is composed of a self-supporting steel-frame structure, aligned, fitted or superimposed on other units, which, in the end, make up the whole house. Sekisui Heim makes available up to 70 types of Units, of which 40 are cuboids varying in its extension, width, and height, and others are in trapezoidal formats, among others (Figure 1).

The Sekisui Heim Residential Houses "HAPPS" technology was developed by the company itself as to reduce recurring errors in component selection while introducing a new class of house in the factory. As these introductions are frequent, errors tended to repeat, which led the company to develop the HAPPS system. Concerning internal production flow, the company's architects firstly designed a custom home from a specific class, which combined standard units. In the selection of the components, there was always a recurring error rate of 5%, which was the same amount as the company's profits. In a worse scenario (the introduction of new classes), there was an initial error rate of 30% until the staff learned how to deal with the innovation. Sekisui then decided to acquire 70% of a specialized company shares, with a background in the development of expert systems based on a "knowledge base" to create the HAPPS (FEIGENBAUM et al., 1995).

Figure 1 – The "Unit" method

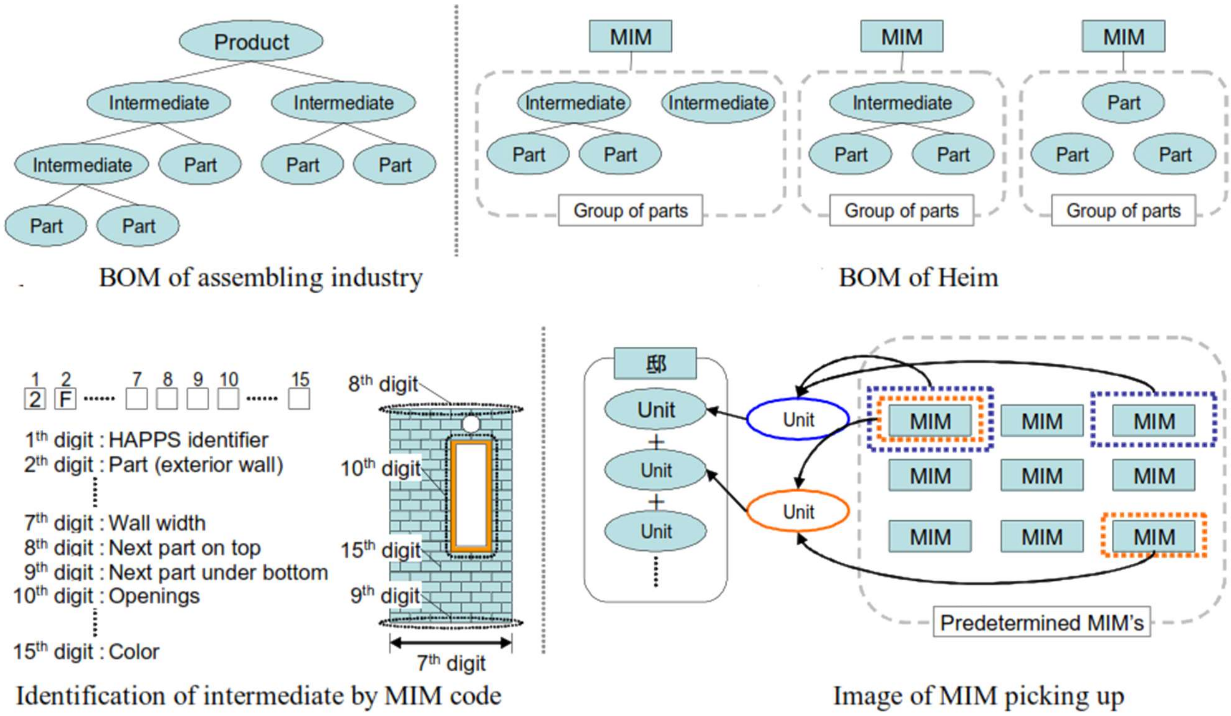


Source: FURUSE, J., (2006)

According to FURUSE (2006), HAPPS allows the customization of residences in a high-performance level, allowing the option of joining approximately 30 thousand parts per house, among more than 300 thousand pre-listed in the company's databases.

In HAPPS all parts are processed separately, per floor. Some key roles are of meaningful insight into the system: labeling or BOM (Bill Of Materials) provides an ultra-refined parts mixture, which allows design freedom for the customization. The BOM concept is familiar in other industries, taking as a principle the "explosion" of the product in blocks and parts. In HAPPS, this concept was widened by creating "imaginary" blocks, which are groups of closely related parts. The identifiers of these parts are called MIM (Menu Item Master) codes. MIM codes are formed by several digits indicating, for example, on a wall, its adjacent elements, color, dimensions, boundary conditions, and so on. Each digit indicates an attribute and its value, the attribute type, as shown in figure 2 below.

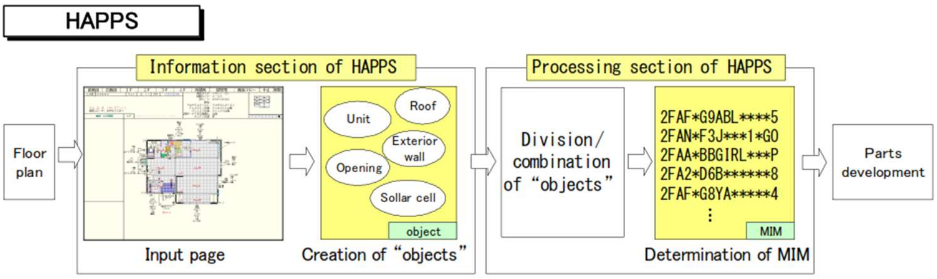
Figure 2 – MIM coding logic



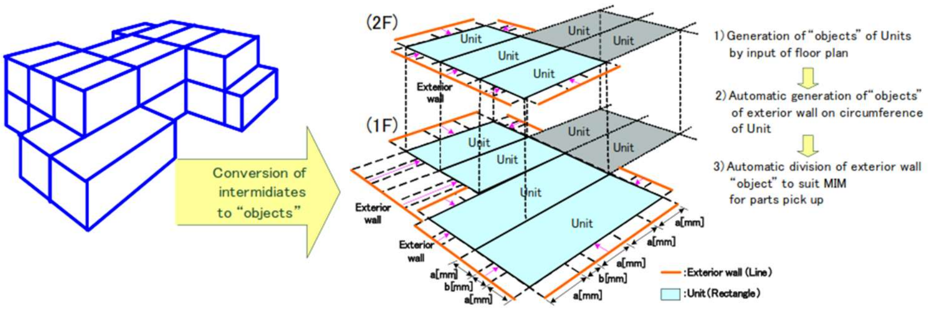
Source: FURUSE, J., (2006)

In the HAPPS system, the CAD is linked to "objects," created from the geometric entities of the drawing. So, we got, for example, the outer lines of the Units to be associated with the "outer wall" object. Each section of line in the drawing corresponds to an outer wall which, in turn, corresponds to a MIM. Thus, objects are related to MIMs in a ratio of 1:1 - each object is equivalent to a MIM (which, in turn, is a group of parts). Through the composition of MIMs and their binding relationships, precedence and other attributes, the objects end up creating a virtual model of the house, for automatic production, in the factory (CAD-CAM system).

Figure 3 –The HAPPS System



Heim Automated Parts Pickup System 'HAPPS'



Conversion of intermediates to "objects"

Source: FURUSE, J., (2006)

Finally, the integration of HAPPS information with the production schedule will generate instructions for workers and machinery in the factory, in binary (CAM) or printed form, reinforcing the JIT as advocated by Lean Production. As for the reliability and efficiency of HAPPS, the numbers attest to it: the error rate of operation in 2015 was 0.017 errors per household, and the correct response rate of the MIMs was, in the same year, 99.5%. Approximately US$ 3.5 million has been invested in the development of HAPPS and similar tools (for wood-frame construction system and small buildings). The savings generated by reducing recurring errors to almost 0% is US$ 8 million annually (FEIGENBAUM et al., 1995).

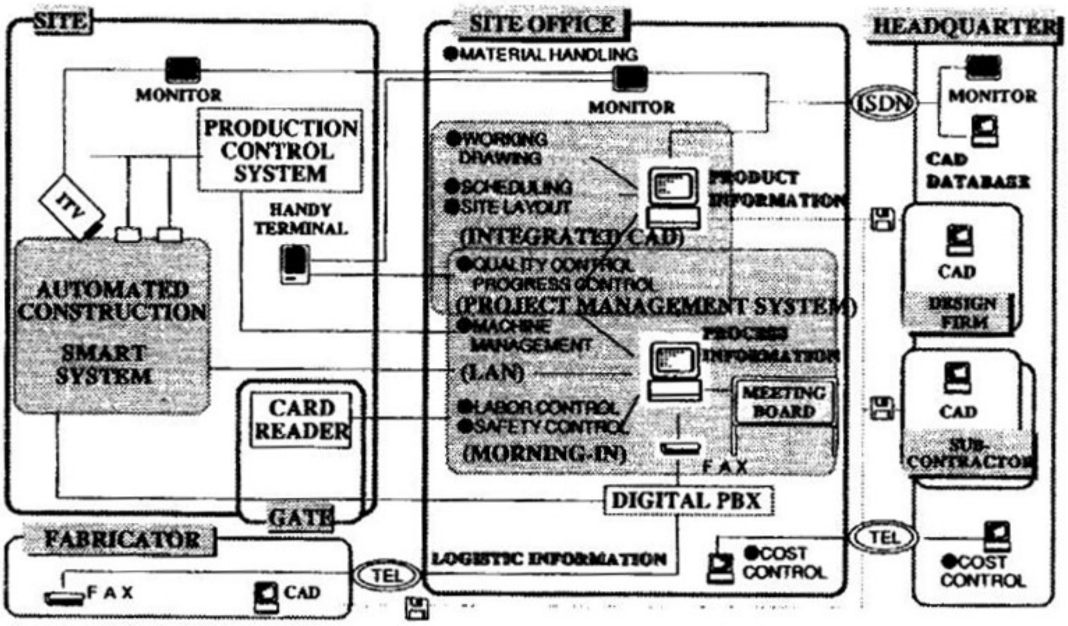
3.3 The Shimizu SMART system

After the success of large-scale prefabricated houses and the attempt to introduce robots for specific tasks on the construction site, Japan's largest construction companies realized that it would be necessary create a structured, on-site factory environment to take advantage of newly created specific tasks robots. These robots, while increasing the productivity of the tasks in which they were applied, were not initially connected to other systems, requiring considerable time to be transported and configured, to start the operation, and yet disrupted other ongoing activities in the construction site. They had to be integrated through a system that employed IT.

Shimizu company developed, then the SMART system (Shimizu Manufacturing system by Advanced Robotics Technology) for massive buildings construction (MIYATAKE et al., 1993) which integrates a wide range of design, planning, and management of building activities, as well as controlling the automation systems of various processes in the construction site. Two main reasons for its adoption were raised: first, to allow the development of entirely autonomous and efficient building systems and, secondly, gaining a considerable advantage in the company's communication between different areas by making information exchange feasible.

This fit to the CIC strategy as to associate the resources, the technologies, the processes and organization to optimize marketing, sales, management, engineering, design, procurement and contracting, construction, operation, and maintenance within Shimizu (MIYATAKE et al., 1993). Figure 4 illustrates the integration of information within the SMART system of Shimizu.

Figure 4 – Information integration in Shimizu SMART system



Source: MIYATAKE *et al.* (1993)

The following lists the expected benefits of the system (MIYATAKE et al., 1993):

- **Operational** : (1) Increase productivity in design and construction through automation; (2) cost reduction; (3) optimization of design and planning time; (4) improvement in the quality of design and construction; (5) improved coordination and management; (6) integrated design; (7) flexibility in the design and construction of new buildings; (8) simultaneous enhancement performance of various departments; (9) improved communication through the rapid data availability, and transmission; (10) avoid data re-entry into design and construction processes; (11) robotics employment opportunities; (12) subcontractors electronically partnership opportunities with, suppliers, insurers, banks, sellers and investors.
- **Strategic** : (1) improvement of the competitive advantage in the market by specialization in the CIC; (2) gain of expertise ; (3) better relationship with the customer; (4) improvement of the company image; (5) increase of the market share; (6) less dependence on skilled labor force; (7) keeping ahead in the use of technology; (8) administrative improvement from an individual system by department to a global optimization (integrated system at the company level).

4. PROPOSITION

For SABBATINI (1989), techniques, methods, and systems are interdependent and interrelated concepts, consisting of the same thing, but on different scales. Thus, "Constructive Technique," "Constructive Method," "Constructive Process" and "Constructive System" are complementary concepts with subordination relation between them. Therefore, it remains clear that the method corresponds to a set of operational processes, within a sequence. The author warns about the relation of subordination of the technique to the constructive method, since that a constructive method applies to different parts of the building.

A constructive system can be greatly benefited by the process and form of project development as it deals with higher complexities and, as such, requires an integration of different disciplines from its initial design conception. In other words, BIM, VDC, and CIC, as products and processes, have much to contribute with the concept of Constructive System since they allow the design automatic generation and modification.

Therefore, there is an immediate and interdisciplinary synchronization provided by BIM, VDC, and CIC that not only constitute a technological breakthrough, but rather than a need for capable, constructive system nowadays, as we initially suggested.

It is proposed, based on what has been exposed throughout the article, that the definition of Constructive System can be re-written by adding the snippet underlined as " *A constructive process of high levels of industrialization and organization, of elements and components that are interrelated and fully integrated, **within a technology system information**, through the process.*"

5. CONCLUSION

In this paper, a review of the definition of Constructive Systems was proposed, in order to add the Information Technology subject, in particular, BIM, VDC, and CIC, since they play an essential role in the AECO and, in general, for all the manufacturing industries. After presenting the concepts of BIM, VDC, and CIC, they were evidenced, through examples, namely: the **product** (modular, with a sizeable pre-manufacturing employment), the **production technology** (robotized automated construction), and the **organization** of production (JIT, considering the construction companies as "assemblers" of houses or buildings. Within this environment, we understand that the production chain is responsible for delivering components to the production line with several degrees of complexity in order to be in synergy with Information Technology. This work considers as crucial, the way towards industrialization as a way of dealing with recurring problems in the AECO.

6. REFERENCES

AMEMIYA. **BIM Revolution for Japanese House Maker**. Tóquio, 1 nov. 2013. 30 p. (IDDS & BIM Oneday Seminar).

BERGIN, M. **A Brief History of BIM.** Public. por Architecture Research Lab. Berkeley, CA. Disponível em <http://www.architectureresearchlab.com/arl/2011/08/21/bim-history/>, Última atualização em 07/12/2012, Última verificação em 16/06/2017.

CARR, N. **IT Doesn't Matter**. Harvard Business Review, May 2003.

EASTMAN, C. M. **BIM handbook:** A guide to building information modeling for owners, managers, designers, engineers, and contractors. Hoboken, N.J: Bookman; Wiley, 2008.

FEIGENBAUM, E.; RICH, E.; WIEDERHOLD, G.; HARRISON, M. **Advanced Software Application in Japan.** Noyes Data Corporation, 1995.

FERRO, S.; COSTA, J. P. de O.; LEFEVRE, J. E. de A.; CONTIER, L. A. **A história da arquitetura vista do canteiro:** Três aulas de Sérgio Ferro. São Paulo: GFAU, 2010. 120 p. ISBN 9788560467013.

FURUSE, J.; KATANO, M. **Structuring of Sekisui Heim automated parts pickup system (HAPPS) to process individual floor plans**. *International Symposium on Automation and Robotics in Construction* (ISARC), p. 352-356, Tóquio, 2006.

GANN, D. M. Construction as a manufacturing process? Similarities and differences between industrialized housing and car production in Japan. **Construction Management and Economics**, 14, 437-450, 1996.

IKEDA, M.; SEKIHARA, Y.; ITOH, N. **Construction planning system for high-rise buildings using an object-based model.** *Proceedings of the International Workshop W78*, CIB, p.283-296, 1996.

JOHNSON, W. **Lessons from Japan: A comparative study of the market drivers for prefabrication in Japanese and UK private housing development**. London, UK, 2007. 58 p.

KHANZODE, A.; FISCHER, M.; REED, D.; BALLARD, G. **A Guide to Applying the Principles of Virtual Design & Construction (VDC) to the Lean Project Delivery Process**. Relatório Técnico, Stanford, CA, USA, 2006. 47 p.

KIERAN, S.; TIMBERLAKE, J. **Refabricating architecture:** How manufacturing methodologies are poised to transform building construction. New York: McGraw-Hill, 2004. xiii, 175 p.

KUNZ, J.; FISCHER, M. **Virtual Design and Construction:** Themes, Case Studies and Implementation Suggestions. 14. ed. Relatório Técnico, Stanford, CA, USA, 2012. 53 p.

LINNER, T.; BOCK, T. Evolution of large-scale industrialisation and service innovation in Japanese prefabrication industry. **Construction Innovation**, 12 (2), p. 156-178, 2012.

MIYATAKE, Y. **An automated construction system for hi-rise buildings:** An example of Computer Integrated

Construction. *Proceedings of the CIB World Building Congress*, Montreal, Canadá, 1992.

MIYATAKE, Y.; YAMAZAKI, Y.; KANGARI, R. **The SMART system project**: a strategy for management of information and automation technology in computer integrated construction. *Proceedings of the first International Conference on the Management of Information Technology for Construction* (CIB W78), 1993.

MCGRAW-HILL CONSTRUCTION. **Prefabrication and Modularization:** Increasing Productivity in the Construction Industry. Relatório Técnico, Bedford, USA, 2011. 56 p.

SACKS, R.; PARTOUCHE, R.; Empire State Building Project: Archetype of “Mass Construction”. **Journal of Construction Engineering and Management**, 136 (6), 2010. doi:10.1061/(ASCE)CO.1943-7862.0000162.

SABBATINI, F. H. **Desenvolvimento de métodos, processos e sistemas construtivos:** formulação e aplicação de uma metodologia. Tese de doutoramento, Escola Politécnica da Universidade de São Paulo, SP, 1989. 207 p.

YAMAZAKI, Y. **3D/BIM applications toward construction innovation**. Tóquio, Japão, 1 nov. 2013. 32 p. (IDDS & BIM Oneday Seminar).