BIM technology application to propagate the knowledge and information for design changes and modifications throughout the product development cycle

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Abstract. A design change may be considered a modification in a particular aspect of this design which has already been released and delivered (production phase) or even during its conception and development phase. Depending on the complexity and stage in the life cycle of the product where the change process is triggered, these changes may take from a few hours to several months to re-adapt the referred design. By applying concepts such as Parallelism, Concurrent Engineering, or most recently, Digital Manufacturing, it is imperative to guarantee that the resulting information about design changes is accurately propagated, reaches all involved stakeholders. Regarding Information and Knowledge Management, the emerging of new technologies such as Cloud Computing, Web Services or more specifically BIM (Building Information Modeling) have boosted the integration of all information projects in collaborative online environments. This paper further explores possibilities to use BIM (Building Information Modeling) technology for organizing and collaboration of the information and knowledge that comes with design changes through the entire products' lifecycle.

Keywords: Design Change, Product Life Cycle Management, Building Information Modeling.

1 Introduction

A new product design is a process thar implies stages, from the conception (focus on creation) to its manufacture (focus on manufacturing) and subsequent maintenance and disposal (focus on operation). Considering the uncertainties, decision points, and improvement opportunities, which occur throughout this cycle, concept changes, functionalities, and constructive details are inherent to the process. In short, changes to how planned, how designed, how built, how sold, how operated, and how maintained [1].

According to [2], the need of change in a product development is caused by i) Correcting a design error which becomes evident until either testing and modeling or customer use discloses it; ii) A change in customers' requirements leading to part of the product redesign or iii) a material or manufacturing method change. This may be caused by material unavailability, a supplier change, or compensating a design error. There are always consequences associated with these causes. Among them: Difficulty in measuring the change's impact [3], the need for input data review, reworking on already manufactured components/parts/subsystems [4], or the financial impacts caused by non-estimated costs. A change occurs throughout the entire product life cycle, from the moment when a concept is first selected up to when it finally goes out-of-service, yet activity differs significantly based on the stage of the product's lifecycle.

No matter which stage, many stakeholders (or actors) are involved, either within organization like the engineers, designers and planners, or external stakeholders, mainly customers and suppliers. Furthermore, as pointed out by [5], records need to be kept on when the changes have been done, and what were the changes, and when these changes are effective. Also important is the statement by [6]: "interested stakeholders engaged at the design, manufacturing, operation, and maintenance steps of a product are entirely independent from each other". Summarizing, in the change context, there are formalization, availability, and collaboration demands within the product cycle.

Significant collaboration has been given by [7] that "is critical to understand product (built object) data, master data, transfer data and, especially, data governance: who produces, modifies, utilizes or owns the data and how these roles possibly change during a built object lifecycle".

On this basis, numerous methods have been developed to manage a built object data modification where one of the most relevant areas being worked on through interoperable file formats across multiple platforms [8]. Along these lines, at the end of the 1990s, a structure emerged aimed at avoiding interoperability problems in the execution of projects: the IFC (Industry Foundation Classes).

An IFC file is an open and non-proprietary file format. It can be used to exchange and share data, during the design, construction, management, and maintenance phases, between all figures and the various applications developed by different software houses without the need to support native (proprietary) files [9]. Often associated with the IFC terminology, technology is increasingly used in construction projects called BIM (Building Information Modeling). According to [10], a Building Information Model is a digital representation of a construction project's physical and functional characteristics. In this model, there is an equivalence between a real object and an equivalent digital object. In a simplified way, the relationship between IFC and BIM is that, in technological terms, it is possible to export a BIM model to an IFC format. By sharing all information in an open format, such as IFC, all actors in the development project can access relevant information when needed so that everyone can work together efficiently and collaboratively.

Thus, considering that the management of design changes is a socio-technical system [11], the efficient use of information and communication technology (ITC) tools is a success factor in reducing, in a way collaboratively, the impacts of changes within the product development process. Therefore, this article aims to evaluate procedural, organizational, and technological aspects that organizations must observe to use BIM models effectively in their product development processes.

2 Design Change in the Product Lifecycle

Conceptually, there have been several studies on aspects of design change, which have defined this subject. According to [5], a design change is a product component modification that occurs after it has gone into production.

In a more comprehensive way [11] defines design changes as “changes to parts, drawings or software that have already been released during the product design process, regardless of scale change”. One last, by [12] defines "change as any kind of project document modification by either the owner, owner's agent, or project engineer". These three assertions above provide an insight about the scope, the impacts, and the stakeholders involved in a project change task. In terms of scope, it is important to introduce one more concept, where project changes are part of, which is PLM (Product Lifecycle Management).

PLM has emerged since the late 1990s aiming at covering the entire product's useful life cycle, i.e., from the initial idea to its disposal [13]. The "life cycle" approach has now made engineering information increasingly accessible to all stakeholders, whether internal or external. Not only engineering information, but also applications, processes, people, work methods, and equipment [8]. There is a business development trend to focus on the organization's key competencies, leading to an enhanced collaboration between partners, suppliers and contractors A relevant aspect to highlight is related to stakeholders, whether internal or external. There is a business development trend to focus more on the organization's key competencies, leading to an enhanced collaboration between partners, suppliers, and contractors [1]

However, to enable an organization’s-controlled integration with external agents, collaboration tools and methods had to be further developed. Along this path, there is another extremely strong concept: PDM (Product Data Management), which has become a cornerstone for organizations' digital operations systems [14].

The PLM and PDM framework also include other technological tools, such as ERP (Enterprise Resource Planning), CRM (Customer Relationship Management), and CAD (Computer Aided Design). Fig. 1 is a graphic representation to show how all these elements are related to each other within the Design Change Management process.

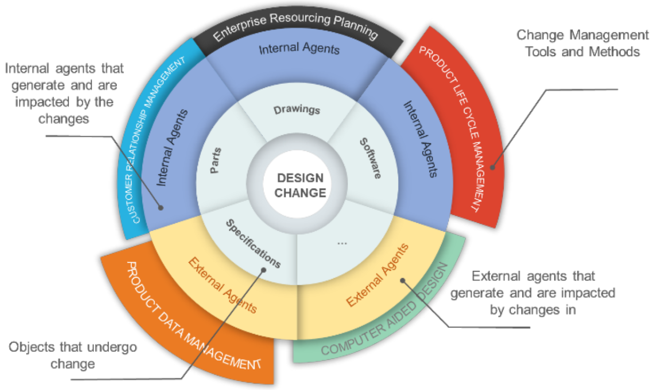

Fig. 1. Relations within the Design Change Management process

3 Building Information Modeling (BIM)

All developed technologies and methods, summarized on the previous section, described the non-integrated participation of stakeholders involved in design change management. By "nonintegrated" is meant the information exchange between the components, from the IT point of view, is not performed within a single data platform. Information about geometry and components' position, for example, will be stored within CAD tools. The basic data such as units of measurement or quality requirements, on the other hand, belong to the domain of ERP software. The design project planning is also contained within the ERP linked to PM tools. Such "discontinuities" in the database interfaces make it harder to determine two critically elements of a design change: their impacts and consequences on the design project.

Professor Charles M. Eastman created the concept of BDS (Building Description System) in 1974, which would be a system to improve the strengths of a building project and reduce its weaknesses [15]. The first use of the term Modeling Building Information, in 1992 by [16], was a paper that discussed multiple views on building modeling, which has been transformed into BIM (Building Information Modeling). Since then there has been a shift of paradigms for handling project aspects in an integrated way [17]. Despite not being a new initiative, it has spread only through the availability of higher-capacity and affordable data processors on the market [18], BIM models have brought a new approach of project delivering, by fostering people, systems, business structures, and practices integration in a collaborative process [19]. BIM is a combination of both geometrical and functional, qualitative, and quantitative contents. BIM model may be summarized according to Fig. **2**: through people using technological procedures, organization accomplishes more collaborative work.

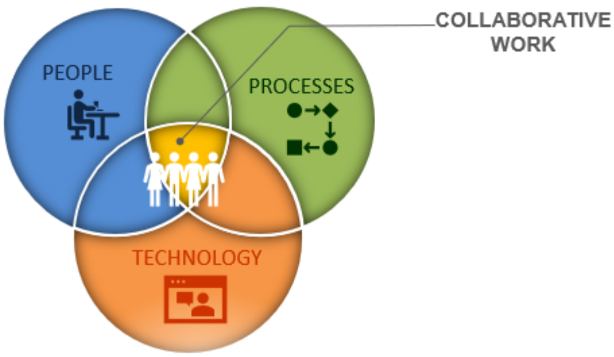

Fig. 2. Simplified BIM model

Technology encompasses the required infrastructure for operation, as well as the software and hardware, data traffic and security, besides the users' training. Any technology-related choice must be properly evaluated, including the organizational business model, the business strategies, and financial investment capacity. On the other hand, focusing on people is also a key part of the implementation strategy [18]. Given that BIM has collaborative work as one major potential, the staff team members should be skilled in both internal and external team relationships. Furthermore, their ability to be flexible for changes and have cognitive capability to take up new concepts and ITC practices.

Other skill to be observed and developed by the teams who are involved with BIM models is the communication ability: to identify errors or potential enhancement and to report them at the right time to the right person, and by a very effective way as a whole, with the appropriate information and detail level, in order to support decision-making and required actions to fix or improve the process [18]. A virtual process itself is as good as the people who operate it. If the staff is not well prepared for the resources, if BIM tool operators do not have expertise and transdisciplinary knowledge about the projects, if designers have no experience of the construction execution, and if the other staff involved in the project work in an isolated and non-collaborative way, new technology will not reach its optimum level. The BIM process focus is related to the information structure linked to activities, components, elements, and processes which may occur throughout the cycle. BIM process adoption, thus, implies the company's operational processes to make the implementation process structuring viable.

If a BIM model is approached from the interoperability standpoint, [19] then, BIM approach provides a comprehensive definition as a "methodology of managing essential construction design and the design data in digital form throughout its entire lifecycle". This means that beyond a 3D viewer and detailing, BIM models offer benefits including cost savings, delivery time acceleration, and opportunities for engineering, planning and supply, and waste reduction throughout all design and construction phases. Fig. 3 illustrates on interoperability between several elements of a BIM model's processes.

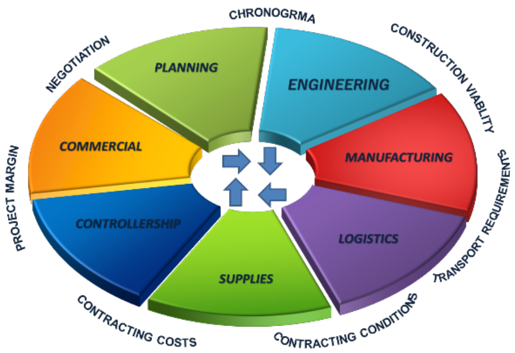

Fig. 3. Interoperability between elements of a BIM model

Technologically a BIM model consists of the combination of information content, geometry, site surveys, and functional data on performance, materials, and quantities. For many experts, BIM involves dynamic management of data and information that are generated by and used during the design lifecycle [20]. Fig. 4 illustrates integration between different technologies involved in information management.

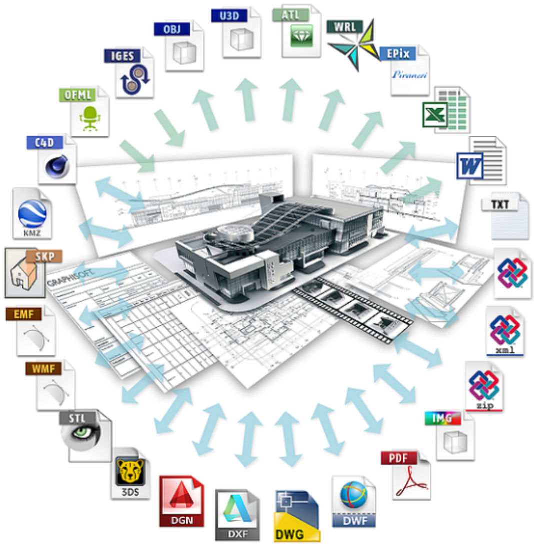

Fig. 4. Integration between different technologies involved in information management.

4 BIM Modeling within Design Changes

Concerning changes identification and comparison between different versions for the same design, current 2D and 3D CAD software can very efficiently identify and indicate geometry or component position changes. Some of these include Autodesk® Revit®, Vico Doc Set Manager™ or Solibri Model Checker™. [21]. Once design project changes are taken into the framework of business processes, ERP and DMS (Document Management System) softwares are also equipped with the ability to detect and report on these changes. For example, component changes with purchase orders or production orders at the manufacturing stage. Also, identification of the installed base of components/products or systems that a project change will impact.

There have been many studies done, on this research stream, identifying and propagating the design changes. Yet they are focused on building construction projects. For example, [22] has done a comprehensive study on Pharmaceutical Sciences Building design, which is built in Vancouver, Canada, at UBC (University of British Columbia). Following a similar approach, [23] has developed a model where changing and impacting were the position on a building's walls and doors. Also [21] developed important research, for what the author called "green features", focused on energy efficiency and conservation aspects.

But, once arguing an adaptive and integrative BIM ought to be able of maintaining the data consistency throughout the whole construction model [22] BIM model dealing with product lifecycle phases becomes advisable.

When considering a BIM model creation approach to design changes throughout the product lifecycle, there are important elements to work on: i) change points, ii) change consequences, and iii) change propagation.

By change points, is meant what has to be observed when identified a need for design change. Changes consequences are the impacts that the change points will undergo. Last, by change propagation, is meant what kind of adjustments must be made to products' lifecycle agents/objects after design changes have been approved. Graphically Fig. 5.

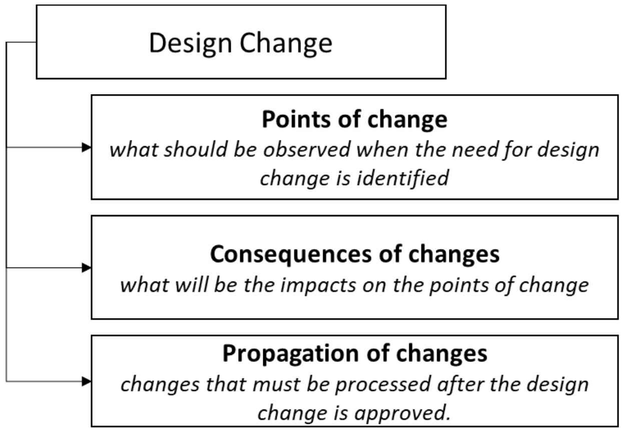

Fig. 5. BIM model focused on design changes in the PLC.

These three elements take place in two distinct phases within the design change process: 1) decision-making - whether a change will or will have to be implemented and 2) updating - to make the updates on the design objects. During the decision-making step, it's important be clear: i) why this change has to be made, ii) what change agents - whose areas/parts have to evaluate the change impacts throughout the whole product cycle, iii) which objects must be evaluated by actors, iv) check list - what has to be checked, v) analysis - what has to be checked on the identified objects by the actors, v) analysis - what has to be checked on the identified objects by the actors, vi) stakeholders - what areas/parties have to be reported after all analysis has been performed, vii) decision - which area/departments have the approval authority to make the change. Sequentially at the update stage, it is identified: i) which areas/stakeholders are supposed to make the updates that have been identified and approved, ii) which objects must be maintained (be preserved) and, closing the cycle, the areas/stakeholders who must be communicated about the changes made. Fig. 6 presents the fundamental steps of the design change using BIM Modelling.

5 Conclusion

Brazilian Federal Government has officialized the National Strategy for Building Information Modeling (BIM) Dissemination, or BR BIM Strategy, which aims at promoting a proper environment for the methodology investment and its dissemination in Brazil. One of the stipulated goals is increasing BIM use 10-fold, so 50% of the civil construction GDP may have adopted the methodology until 2024 [24]. Such information

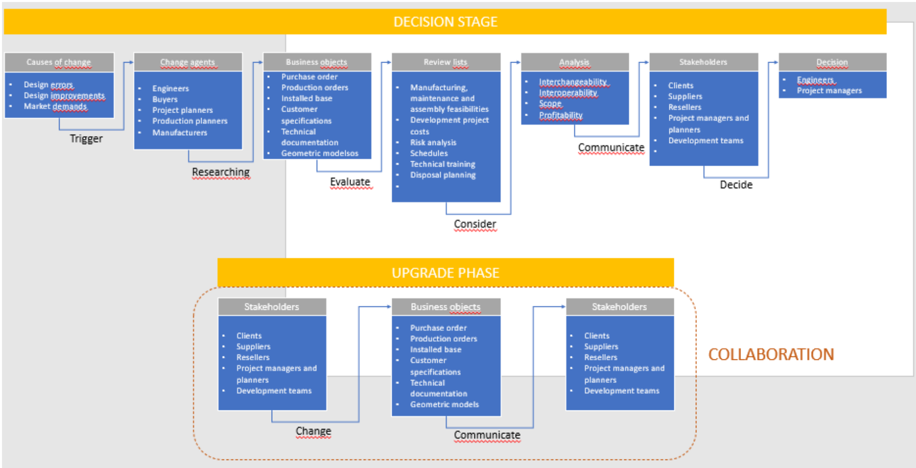

Fig. 6. Proposed BIM Modeling within Design Changes.

provides some perspective about the significance of this methodology use in construction project management. Productivity gains, sustainability, control, transparency, and financial return are quite considerable. These gains, obviously, will demand not only financial outlays (capital investments), but also investments in training, reorganization of work teams, among others. With respect to models' application and an efficient change management that occurs throughout product development projects, working with BIM technology has been very efficient as well. One major reason for this is the opportunity, as several studies and practical applications have demonstrated, to organize the information coming from the different parts that integrate the complete lifecycle and products development cycle and therefore to increase mitigating change effects on projects.

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