Contribution to the study of collaborative working in BIM-based projects in the context of public works

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Abstract –

The great development of Information and Communication Technology (ICT) in recent years, especially network-based and cloud-based technologies, has led to a significant increase in efficiency of Building Information Modelling (BIM) platforms, which motivated a radical change in project managing in Architecture, Engineering and Construction (AEC) companies through implementation of collaborative working environments. However, the methodology used for implementing all the involved concepts has a direct influence on the results in terms of quality of AEC projects and efficiency in their development process. This paper focuses on the similarities and differences between two collaborative arrangements for BIM adoption in AEC projects, with a view to choosing best practices for civil construction works management and inspection offices in the context of public works in the Brazilian federal government. The first arrangement uses software from the same developer and proprietary formats, while the second uses software from different developers and formats suitable for interoperability between them. Based on the results, this work points out the limitations, advantages and disadvantages of using both arrangements, indicating research perspectives for industry and academia.

Keywords – Collaborative Design; Building Information Modelling; Public Works; Interoperability.

1 Introduction

Construction projects have become larger and more complicated in the first decade of this century. The amount of information required has been increasing, leading to greater complexity in the collaboration between the designers themselves and between them and various possible stakeholders.

Among several technologies appeared in the Architecture, Engineering and Construction (AEC) sector, certainly Building Information Modelling (BIM) is the most important. BIM is an emerging technology focused methodology that can be used to improve the performance and productivity of an asset´s design, construction, operation and maintenance process [1].

According to Succar, BIM is described as a digital representation of physical and functional characteristics of a facility [2]. Succar also describes BIM as a set of technologies, processes and policies enabling multiple stakeholders to collaboratively design, construct and operate facility in virtual space [3]. Eastman et al. describe BIM as a modelling technology and an associated set of processes to produce, communicate and analyse construction models [4].

This study focuses on the similarities and differences between two collaborative arrangements for the adoption of BIM in AEC projects, to choose best practices for civil construction works management and inspection office in the context of public works in the Brazilian federal government, notably Brazilian Army Regional Works Offices. Based on the results from two case studies, we aim to discuss about limitations, advantages and disadvantages of each arrangement, providing useful information for future implementation of collaborative BIM-based working environments.

Section 2 presents research background. Section 3 presents possible BIM collaborative arrangements used in two case studies. In Section 4, the results obtained in these case studies are discussed. Section 5 proposes possible applications in the context of public works in the Brazilian federal government. Finally, Section 6 concludes the paper.

2 Research Background

In this section, the main characteristics of collaboration, interoperability and application of BIM in the public sector are presented.

2.1 BIM in the public sector

Public sector plays an important role in leading the industry towards BIM adoption. BIM implementations continue to increase intensively as more and more government bodies and non-profit organizations of various countries worldwide implemented BIM in their projects and provided different BIM standards and solutions [5].

It becomes important in public sector to review and evaluate the current performance of all processes, to ensure the public sector obtaining a greater value for the money in their construction projects [6].

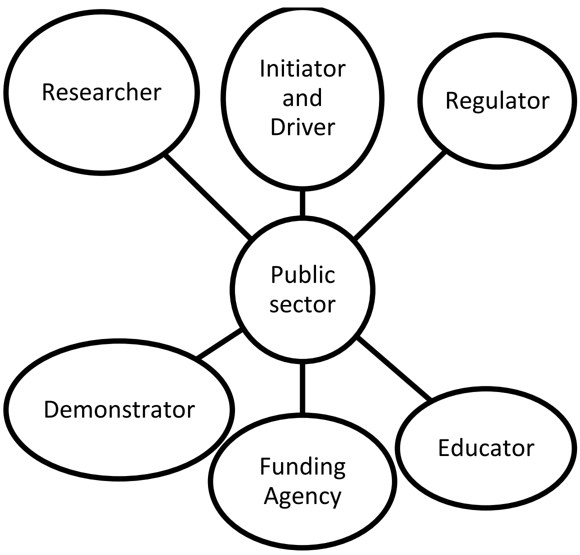
Many countries around the world have adopted BIM technology. The United States is believed to be one of the pioneering countries for BIM adoption. Many public-sector bodies at different levels in the United States have established BIM programs and set up BIM goals, implementation roadmaps and BIM standards [5].

Apart from the United States, many countries in Europe have embarked on significant BIM implementations, like Netherlands, Finland, Norway and United Kingdom. Although BIM adoption in the public sector came later in Asia, BIM has now developed rapidly in Asian regions, for example, in Singapore, Hong Kong, China and South Korea [4;5].

Succar [3] listed the publicly-available guides, reports and visions related to BIM in Australia, Denmark, Finland, Netherlands, Norway, the United States and a consortium of organizations in Europe.

Based on the review and comparison of BIM variables and implementations in different countries, six major roles of the public sector regarding BIM adoption were analyzed in [5], which are initiators and drivers, regulators, educators, funding agencies, demonstrators, and researchers, as illustrated in Figure 1.

Figure 1. Roles of the public sector for BIM adoption. (adapted from [5])



Unfortunately, BIM experiences in Brazil related to these roles of public sector have been sparse and not coordinated. Possibly the first state action with public results with respect to BIM projects took place in 2010, when an initial version of a BIM component library for state program "Minha Casa Minha Vida" was developed. Since its completion, this library has been largely distributed in Internet, being a reference for popular housing projects.

The first bidding process that refers to BIM in Brazil was also launched in 2010. Several constructions for the 2014 World Cup in Brazil and the 2016 Olympic and Paralympic Games in Rio de Janeiro were developed with BIM processes; however, it was an option of contractors themselves, and not a state imposition.

Perhaps the most successful BIM experience is that of the State of Santa Catarina, where the developers of two health institute projects were selected to be contracted in 2014/2015 by using technical evaluation of proposals with help of Solibri Model Checker [7].

In other public institutes, BIM has generally been used in common tasks like quantification take-off and geometric modelling of civil engineering projects [8].

In another point of view, Brazilian Army has improved real estate management quality by using the Unified System of Works Process (from the Portuguese "Sistema Unificado do Processo de Obras", whose acronym is OPUS), an information and communication technology system developed by its Directorate of Civil Works. Nascimento at al. describe OPUS as an integration of specialized Enterprise Resource Planning software with construction building information models, created for supporting the built environment lifecycle management including buildings and assets related to AEC [8,9].

OPUS was internationally recognized as unique in the world in BIM technology (BIM online collaboration, standards and protocols) for infrastructure and public sector [8].

2.2 Collaboration

The notion that building design is a multi-disciplinary process involving contributions from an increasingly broad range of specialists is well understood and generally accepted. Building design could be described as a cooperative process with brief episodes of collaboration where team members come together to resolve issues through negotiation and evaluation. Collaboration arrangement is traditionally used in AEC. It has revolved around the exchange of 2D drawings and documents. As Eastman et al. explained in their book [4], BIM technology makes easier the simultaneous work by multiple design disciplines. Although collaboration with drawing is possible and used, it is inherently more difficult and slower than working with one or more coordinated 3D models, in which change control can be well managed [10,11,12].

BIM-based collaboration project should be run with programs that provide functions necessary to complete the tasks in each of its phases [13].

Several countries around the world have established or are establishing rules and guidelines for the collaborative process. In the United Kingdom, BS 1192: 2007 establishes the methodology for managing the production, distribution and quality of information in construction, including those generated by CAD systems, using a disciplined process for collaboration in a specified policy [14].

To provide an efficient collaboration environment, the interoperability is an important point that must be solved in early design. This concept will be well described in the next topic.

2.3 Interoperability

No application can support alone all the tasks associated with building design. The interoperability represents the necessity of data exchange by the multiples types of applications, allowing multiples professionals to collaborate with the design. Data exchange between two applications is made by many ways. The principals are: direct link, used when the connection between two applications called from one or both application user´s interface; proprietary file exchange formats, when it is developed by a commercial organization for interfacing with that company´s application, like DXF (Data eXchange Format), by Autodesk Company; public product data model exchange formats, when an open-standard building model is used, e.g. IFC (Industry Foundation Classes) - developed model schema that is able to support a semantically rich representation of a building for use during the life cycle design and management of a project. Despite buildingSMART efforts, exchange of data via IFC still continues with data loss of geometry and information, even in its current version IFC4 [4,11,17].

The first collaborative arrangement presented in this paper is based on the first two ways of data exchange. The second one used IFC to exchange the data between the members of the team.

3 Collaborative arrangements

Two collaboration arrangements are presented for developing projects, with the aim of applying them to a management execution office of public works in the Brazilian Army: the first, using software from the same developer; the second, using software from different developers.

Each one was employed in a different educational project. While the former involved the application of BIM in the construction of a sports school, the latter involved the construction of an elementary sustainable school. Each case study involved the development of its own interoperability, collaboration, and production solutions within a team, which is presented in the next sections.

3.1 Case study 1: sports school

The first arrangement was based on Autodesk solutions contained in Design Suite 2016, which brings together the two most used tools in Brazil: AutoCAD and Revit. A summary description of the used suite products is described in Table 1.

Table 1. Summary description of the software used in case study 1 [4]

Software	Summary description
Autodesk AutoCAD	CAD-based software, used mainly for the elaboration of 2D/3D technical drawings. Autocad is considered as a support tool, not as a BIM solution itself.
Autodesk Revit	Solution developed specifically for BIM, allowing the development of models with features for modeling, quantitative surveying, camera generation, views, captions, tables and interactive tours.
Autodesk Navisworks	Solution that enables AEC professionals to review integrated models and data for better control over project results through interference checking, quantitative extraction, and creation of 4D analysis of the work.
Autodesk Robot Structural Analysis	Robot Structural Analysis Professional provides structural engineers with advanced analysis for large and complex structures.

The sports school project was developed by a group of eight professionals. There were one architect, four civil engineers - including the first author of this paper - and three senior students - an architecture and two civil engineering students. The tasks were divided among the architects and the engineers so that the architecture, structure and installations projects were then developed.

Each program had a specific purpose and usage by the task group, whether or not being part of Design Suite 2016, as shown in Table 2.

For the project development, the federated model was adopted, where several local or central files were created so that they could be linked to each other. In this way, all team members were able to work concurrently the different components of the same or different disciplines, after an initial meeting to discuss the concept of the project and the development of an initial model in Level of Development (LOD)100.

Table 2. Description of software used in case study 1.

Software used	Objective
Autodesk AutoCAD 2016	2D Specific details
Autodesk Revit 2016	3D BIM models
Autodesk Navisworks 2016	Clash detection, 4D BIM Model and quantification take-off
Autodesk Robot Structural Analysis 2016	Structural model analysis
Lumion 3D	Images and 3D videos creation
Adobe Photoshop	Image edition
Microsoft Project 2013	Schedule development
Microsoft Excel 2013	Auxiliary worksheet development

Within each central file, worksets were created in order to make ease the interface and compatibility between all discipline models, as shown in Figure 2.

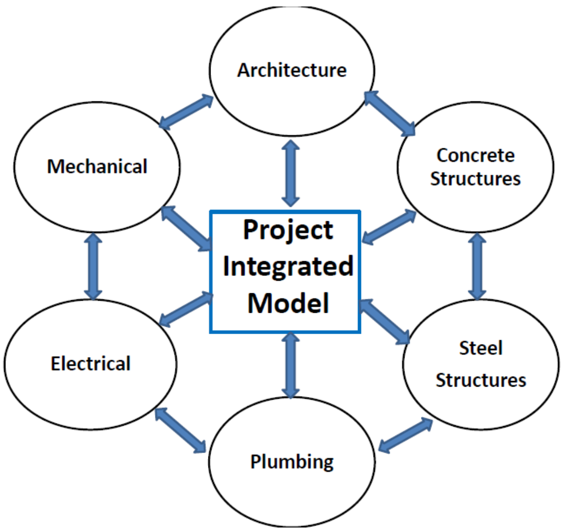


Figure 2. Information exchange between all project disciplines

Each central file was related to a design discipline: architecture, structural (steel and concrete), mechanical, electrical or building installations. As a draft project, all BIM components were modelled in LOD 200, except for a few MEP components available only on higher LOD at pages such as BIMObject.com and Autodesk Seek.

Other specific components developed specially for this work, like those related to gym and bodybuilding apparatus, were stored in a library located in a virtual work environment.

For specific situations, Robot structural analysis files and Navisworks clash detection reports were separated from other folders. All related files to AutoCAD drafts, Revit BIM models, Navisworks reports and Robot structural analysis were deposited in a Dropbox cloud environment, managed by the group coordinator.

Communication between individuals and software was done by direct links or proprietary file exchange formats whenever possible. Priority was given to direct links between Autodesk software that were already available, rather than using the IFC interoperability format, as shown in Figure 3.

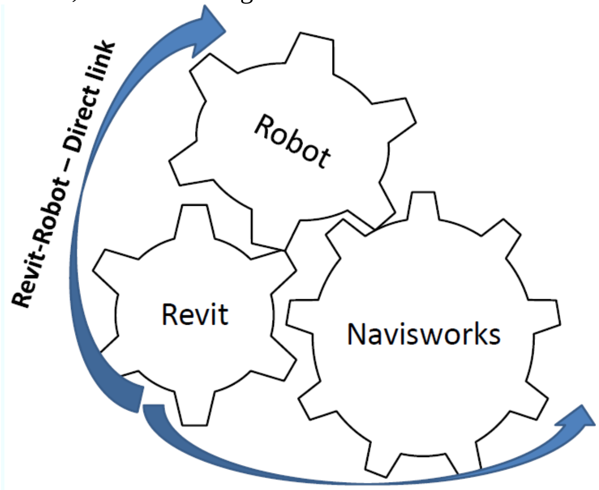


Figure 3. Information exchange inside structure discipline

Work meetings were held weekly and virtual. GoToMeeting application was successfully used for group discussion, project analysis, and action. For written communications about general project information and other questions, Trello application allowed tracking of all project discussions, by means of practitioners' computers or smart phones.

Visual interference control was done throughout the work inside or outside the meetings, either by the manager or by each member of the group.

Clash detection routines through Autodesk Navisworks were performed in rounds. In each round, all models passed through the tool in pairs, and clash reports were received by MEP engineer. According to the orientation of the group coordinator, the models were corrected by the corresponding members responsible for the involved disciplines, starting then a new round of clash detection routines, until full completion of all clashes.

3.2 Case study 2: sustainable school

The second arrangement - where the second author of this paper has worked - was made using several software solutions for AEC design, communication management, model validation and compatibilization. In contrast to Case Study 1, Case Study 2 used interoperability solutions, like IFC format. Table 3 shows all software used in Case Study 2 while Table 4 shows their purpose in this research.

Table 3 Software Use

Software	Use
Graphisoft ArchiCAD 19	Architecture Design
Autodesk Revit 2016	MEP and Structure Design
Autodesk Robot Structural Analysis 2016	Structure Analysis
Solibri Model Checker(SMC)	Model Validation and Compatibilization
Graphisoft BIMx	3D videos creation and presentation

Table 4 Software Feature

Software	Description
Graphisoft ArchiCAD 19	Oldest BIM tool on the market. Intuitive interface and the native library is wide
Solibri Model Checker (SMC)	The software is an IFC reader that performs interference checks and preloaded engineering rules. These rules can be customized by the user with logical instruction. It also has the functionality to coordinate projects, creating a communication log so that the project team can analyze and correct the interferences and inconsistencies found in the model.
Graphisoft BIMx	Software used for virtual walkthrough and video presentation of BIM models in Android operational system.

The aim was to design an Elementary Sustainable School collaboratively by a multidisciplinary team, according to BIM-process premises. The data exchange format used in this project was IFC while the communication between team members was the BIM Communication Format (BCF).

The workflow, shown in Figure 4, begun with a meeting to discuss the concept of the project, resulting in a necessity program. After this, the architecture team developed an initial model. When it achieved a level of maturity that allowed the work of other disciplines, the IFC file was made available. A cloud storage service was used to be the collaborative files repository.

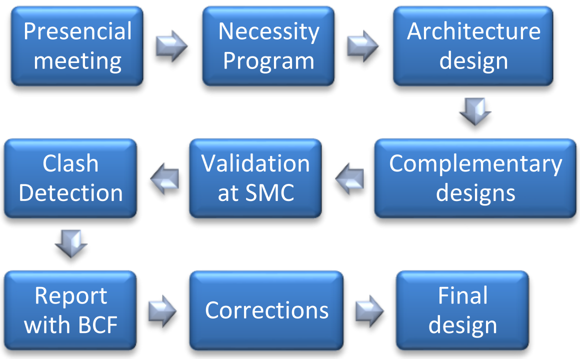


Figure 4 - Design workflow

From this point, the other disciplines developed their projects in their preferred software on the architectural basis while the architecture continued to evolve its LOD to perform compatibility checks.

By the time the complementary designs reached a degree of maturity that could be checked, they were submitted to a validation evaluation at SMC. This validation was related to interferences between objects of the same model, dimensions of environments and considerations about the necessity program and it was done by the designer himself.

Having in hands the designs validated by SMC, a meeting was scheduled to compatible them. All the models were assembled in a federated central model to perform a Clash Detection, as shown in Figure 5.

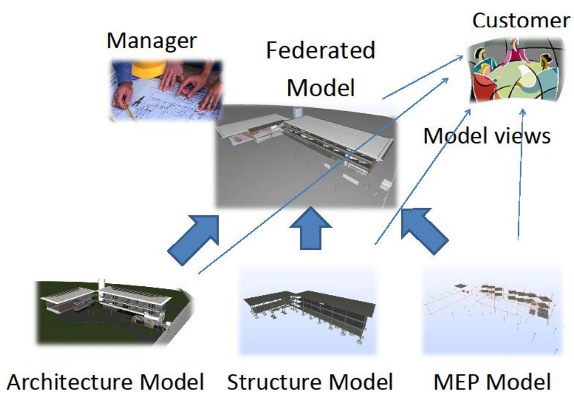


Figure 5 – Federated Model

The clashes were then analyzed by all members and the responsibilities for their correction were defined, if necessary. To report what should be done and who should do it, BCF communication format was used. The BCF is part of SMC and can be viewed by anyone who has the BCF viewer installed. Once the corrections have been finalized, the central model is updated in SMC, as well as the information of the interferences in it.

The used model to work collaboratively is called Federate Model (Figure 5). In a simplified way, it means that there are distinct models, logically linked by the SMC. This implies that a change in one model does not automatically change the other models.

4 Results discussion

In both case studies, the design process has become more intense because of typical collaborative and interoperability features of BIM projects. The solutions in all disciplines were quickly discussed among the task group, during meetings or using network solutions like Trello or Netmeeting.

Designers and their experiences are highly valued in BIM processes because other technical and relational skills and abilities are required. Human relations between professionals have become even more important, requiring the project manager and team members to develop relationship skills.

Weaknesses in design and technical requirements have arisen in both case studies during the components modelling in Autodesk Revit or Graphisoft ArchiCAD, instead of appearing during a theoretical bidding or construction phase of the design.

Weekly, design clash detection rounds were performed by using SMC or Autodesk Navisworks, with the goal of further increasing project maturity, reducing the clashes to the lowest possible level in its final delivery, and enabling a feasible and consistent result.

Unfortunately, interoperability problems have become an important issue in project development, either with Autodesk direct links and proprietary file exchange formats or with IFC interoperability format; three of which are highlight in the following:

- Sometimes ArchiCAD IFC translator did not perform actual representation of some instances, losing some important information;
- Some components like lighting devices, mechanical equipment and ceiling elements were not recognized by modeling software. Modelers were usually asked to launch absent component again and thus continue the project immediately;
- In structural analysis, some nodes and elements were not recognized after having been transferred from Autodesk Revit to Autodesk Robot Structural Analysis. Structural engineers were then asked to review structural model and correct it again, element by element.

All team members have had their productivity increased, despite the problems described above. This may be related to the fact that most people involved have had little or no prior experience with any collaborative arrangement that uses interoperability or network solutions.

5 Application

5.1 Description

The aim of this section is to discuss applicability of one of the case studies presented in this work in civil construction works management and inspection offices of public works in Brazilian federal government.

Brazilian Army, through its Directorate of Civil Works (DCW), a technical and normative support agency, developed the OPUS system – a BIM cloud based platform already described in [9] – to overcome difficulties related to the lack of integrating tools and the existence of several databases that could not be updated systematically and equitably.

The arrival of OPUS enabled DCW to a better work and asset management. Military constructions being built in the Amazon or anywhere in Brazil can now be easily managed by DCW director or by his staff despite the diversity of imposed constraints related to legal, normative, technical, military, cultural and environmental aspects, many of them imposed by Brazil public procurement laws.

All military constructions are managed by 12 Regional Works Offices (RWO), where AEC works are projected and supervised by engineers and architects. However, in contrast to the successfully strategies for developing and adopting of such a city information modeling (or a building information management) tool like OPUS, most RWO are in pre-BIM level, if considered Succar BIM adoption matrix, whose levels of adoption are illustrated in Figure 6 [3]. This is evident because most projects are developed by using CAD-based software with DXF interoperability pattern. BIM proper usage is seen only in a few projects. Only two of twelve RWO have just reached Succar Level 1 of BIM adoption – even if it is used only on architectural models in an *ad hoc* way.

Additionally, there has been only one architectural template in development by DCW; however, it's rarely been used by all RWO. Structural and MEP models, clash detection routines and 4D modelling are still rare and uncommon.

Surveys performed by the first author of this paper in his PhD thesis pointed out the following complaints among engineers and architects working on RWO about

BIM programs:

- Use of BIM solutions – notably Autodesk Revit Architecture – is relatively limited in all RWO;
- There is few incentive in learning of BIM programs;
- Few AEC professionals can discern the difference between Revit and BIM or why it can be so important;
- Only a few can apply the benefits of BIM to RWO activities like design and construction supervision.

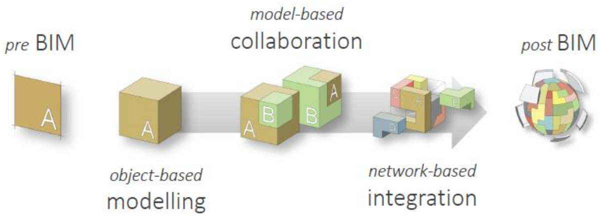


Figure 6 - BIM stages of adoption (adapted from [3])

Most of the constructions developed by DCW have got functional use and no more than three floors, with exception of construction of some residential buildings for military personnel. Their structure is generally of reinforced concrete and its MEP installations do not have great complexity.

Given the BIM conditions in RWO, applicability of case studies presented in Sections 3 and 4 will be discussed bellow.

5.2 Applicability of case studies

First, a solution or set of BIM solutions must be chosen to meet all needs. The two case studies have shown that any of them is suitable to meet their needs. However, it is emphasized that it is difficult to find solutions from only one software factory to meet all requirements, as described in Case Study 1, given the diversity of RWO activities.

Once the BIM software solution has been chosen, a set of defined workflows must be adopted, as also shown in the two case studies, both for the elaboration of the projects – internal standards for modeling – and for clash detection.

Modeling rules should be complemented by the definition of a BIM Execution Plan (BEP) that will be used as a subsidy for the preparation of projects in all RWO and for the contracting of BIM complementary projects.

About BEP, English standard PAS 1192: 2-2013 defines and splits it into two phases, where the first one refers to the implementation, goals and design milestones to be reached, while the second part refers to information about management, planning, BIM solutions and standard methods of BIM adoption [15,16].

BEP must contain an initial set of building component library for model execution and definition of interoperability protocols. It must also enforce all work groups – who work in project design, procurement or construction management – to follow its defined protocols.

The involvement, incentive and encouragement of all stakeholders are of central importance in this process, so that all RWOs have a homogeneous BIM adoption evolution.

Another important factor is the training program of professionals, which may involve basic and intermediate level training of BIM tools defined in BEP and/or management training within each workflow defined in the BEP, focusing on collaborative work practices.

Practical exercises should be done for training project teams. In this way, Eastman argues that it can be done first with a short pilot project, with qualified groups and with a clear goal aligned with each previously presented goal. This long-term training program would aim the achievement of Level 2 in terms of Succar index of BIM adoption [3].

Work can still be expanded to larger projects after having been reached BIM Level 2. More complex network and cloud environments can be used after diversified and trained project teams would be created. Given the unique nature of all project developed – Brazilian Army barracks and headquarters – proprietary cloud solutions like Collaboration for Revit (C4R) or Autodesk A360 must be avoided.

Quantity takeoff engineers will be able to participate in 4D/5D modeling with BIM software e.g. Autodesk Navisworks, VICO Office and/or a proper budgeting software. It is also important the definition of modeling guidelines for quantity takeoff-oriented BIM design, such as proposed in [18]. Hence, budgets and schedule activities would be made more accordingly to the services to be executed in each construction.

6 Conclusions

This study has focused on the similarities and differences between two collaborative arrangements for adoption of BIM in AEC projects. Two case studies have been presented with different interoperability arrangements. While in the first, Autodesk direct links or proprietary file exchange formats have been used, IFC format has been used in the second one.

The aim was to conclude about a future application of one of the case studies in inspection offices of Brazilian federal government, notably the Brazilian Army Directorate of Civil Works and all its Regional

Works Offices located throughout the Brazilian territory.

Although the initial comparison between the given case studies concluded that both could be used in any government office, it must be emphasized that any proprietary solution, with software from a specific developer, can meet all the needs from DCW. At some moment in the near future, IFC interoperability format will have to be used, despite all its limitations.

From performed surveys, one can conclude that the main difficulty for BIM adoption is not the proper BIM solution that will be employed. In general, professionals have got a limited point of view of what BIM really is or what it can do to make their job easier.

Then, the key word of BIM adoption is proper training and an appropriate definition of methods that will make professionals more confident about the outcome everyone wants and expects.

Given all these conditions, a training program and a BIM execution plan – as defined in Section 5 – must be the start point of an integrated BIM adoption in all RWO, instead of an *ad hoc* implementation under the initiative of a few professionals in one or two work offices.

The proficiency in usage of BIM software and the creation of proper network solutions can boost the development of computational tools to improve the existing OPUS system, integrating them with current management tools that already exist.

For that, a definition of a conceptual framework for the public management of military works, both for the management and design of projects, is highly recommended to achieve a better level of BIM adoption.

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