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Virtual design and construction of plumbing systems

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Abstract: Traditionally, the design coordination process is carried out by overlaying and comparing 2D drawings made by different project participants. Detecting information errors from a composite drawing is especially challenging and error prone. This procedure usually leaves many design errors undetected until construction begins, and typically lead to rework. Correcting conflict issues, which were not identified during design and coordination phase, reduces the overall productivity for everyone involved in the construction process. The identification of construction issues in the field generate Request for Information (RFIs) that is one of delays causes. The application of Virtual Design and Construction (VDC) tools to the coordination processes can bring significant value to architecture, structure, and mechanical, electrical, and plumbing (MEP) designs in terms of a reduced number of errors undetected and requests for information. This paper is focused on evaluating requests for information (RFI) associated with water/sanitary facilities of a BIM model. Thus, it is expected to add improvements of water/sanitary facility designs, as well as to assist the virtual construction team to notice and identify design problems. This is an exploratory and descriptive research. A qualitative methodology is used. This study adopts RFI's classification in six

analyzed categories: correction, omission, validation of information, modification, divergence of information and verification. The results demonstrate VDC's contribution improving the plumbing system designs. Recommendations are suggested to identify and avoid these RFI types in plumbing system design process or during virtual construction.

Keywords: Virtual design and construction; VDC; 3D coordination; Virtual prototyping; BIM; Requests for information; RFI

1 Introduction

The coordination of Mechanical Electrical Plumbing and Fire (MEPF) design is a great challenge. The inability of identifying conflicts in 2D-drawings creates delays in the construction process and increases the administration burden due to the identification of conflicts in the field, when budget is already approved. It also produces rework to correct problems unidentified in the design phase and influences the productivity of the ones involved in the construction process [1]. Building Information Modelling can help the AEC industry to point likely problems before the beginning of the construction work [2]. Nevertheless, BIM benefits towards design compatibility are associated with the level of detail [3] – currently named as the level of development – of the Virtual Design And Construction (VDC) resulting model.

The researches about this theme are mainly focused on its conceptualization and only a few examples are about the BIM benefits to MEPF systems [4].

This paper aims to evaluate requests for information (RFI) associated with water/sanitary facilities of a BIM model with the Level Of Development (LOD) 400 [3]. Thus,

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this work contributes to improve MEPF designs, and assists the virtual construction team on observing and identifying design problems.

2 Constructability analysis

Constructability is a concept emerged in late 1970's [5, 6] and it has evolved over many studies [5–8]. Constructability can be defined as the use of construction knowledge and planning experience of design, engineering, construction and supply for design optimization [9]. A constructability analysis framework is suggested in order to reduce construction problems caused by designs and then, it will eventually make company more competitive [10]. When associated with design process, constructability enhances quality and productivity as well as it reduces time, waste and costs, promoting a better building development by inserting the constructor in the design process [11].

Constructability analysis associated with BIM is a relatively new approach and offers new evaluation of construction methods can be performed in a more efficient and uninterrupted way. Currently, it's made with virtual exam of the BIM model [5]. Implement constructability on design process requires a complete disassemble of traditional idea compartmentalization and design team need more building feedback than constructors can give [12].

3 Virtual design and construction

Virtual Design and Construction (VDC) concept can be defined as the use of multi-disciplinary computer models that include product, construction, organization of construction team, operation team and performance requirements aiming to support, public and explicitly, the objectives to integrate design, engineering, construction, operations, business strategies, etc. [13].

Creation of design alternatives in 4D models and prediction of its design behaviors are the main VDC goals [14]. Studies show VDC is a Lean process activator and improve construction design delivery performance [15]. VDC is the way to enhance construction design management and its utilization demands a significant protocol alteration, mentality and traditional behaviors in the construction industry [15, 16].

4 Methodology

This paper is an exploratory and descriptive study. Its analysis unity is about prototyping BIM process and presenting a perspective from a practical BIM implementation.

The methodology used was qualitative. The starting question was “How can VDC contribute to improve MEPF designs?”. A research review about this theme and methodology was done. Then, it was possible to understand each research contribution and use them as a guideline to analyze the data in this paper.

Case study was the research strategy used. This strategy applies for “why” and “how” questions and when focus is on contemporary phenomenon within the real life context [17].

Case sorting occurred whereof information oriented selection [18] to maximize information utility that this case could provide to the research's objectives. A critical case was selected to obtain information that allows logical deductions such as: “If this is (not) valid for this case, so this can (not) be applied to other cases”. The case choice criterion was guided by VDC use in design coordination.

This paper was based on multiple evidence sources: semi-structured interviews taped and transcribed by managing virtual construction analyst and/or civil engineer responsible for 3D model; documental analysis of design coordination reports; communication between contractor and BIM analyst, and analysis of 3D navigation model of construction through Autodesk Navisworks Freedom software. Data collection was conducted considering following operational means that corroborate to validate the reliability of the data collected: use of multiple evidence sources; revision of interview report by interviewed; and development and use of case study database.

The data collection was made through fundamental theory, which was matched with case study as a way to

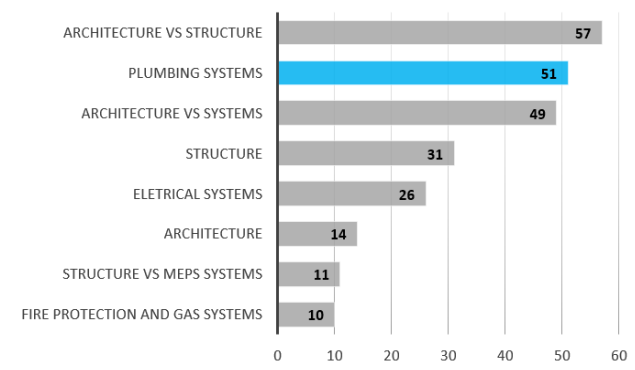


Figure 1: RFI distribution.

treat data and interpret them. The data analysis focused on pattern recognition, construction of explanations and use of logical models, which allowed the comparison between an empirical pattern obtained through case study and another one through prognostic basis obtained from the researches' review. Analytical qualitative strategy was developed with the help of a software to organize, manage and analyze qualitative information. The data categories applied in this paper are the ones which can be observed in Eastman et al's [19] case studies.

5 Results

5.1 Enterprise description

Case study is a project of a 15.925,67 m² floor-area residential building and it has an estimated cost of R\$ 38 million. After the conclusion of the architecture, structure and facility pre-executive designs, the construction/incorporation company chose the intermediary phase execution named virtual pre-construction. In this phase, a BIM model was created with LOD 400, which allowed the constructability analysis, aiming to guarantee in advance the execution of that construction system in a more efficient way regarding time and cost. In order to achieve BIM benefits visualized by the client, it was released to the virtual construction team the past designs and the company's constructive methods. Constructive method contains constructive work execution information, which are not explicit in designs, but it must be considered in the pre-construction phase. An example of this type of information is designs' sequencing. In this case, designs were virtually built in the same way as they are built in reality. Thus, sanitary designs were modelled first and served as base line for further analysis of possible conflicts with the remaining facilities.

5.2 Virtual construction process

167 RFIs related to MEPF designs was identified through coordination model analysis. 51 RFIs were associated specifically with plumbing system design. Hydraulic, sanitary, ventilation and drainage plumbing were part of plumbing systems. Figure 1 shows RFI's distribution identified with highlight plumbing system design, qualitative analysis' subject.

The analysis of the interview showed that design virtual construction process was developed in three stages.

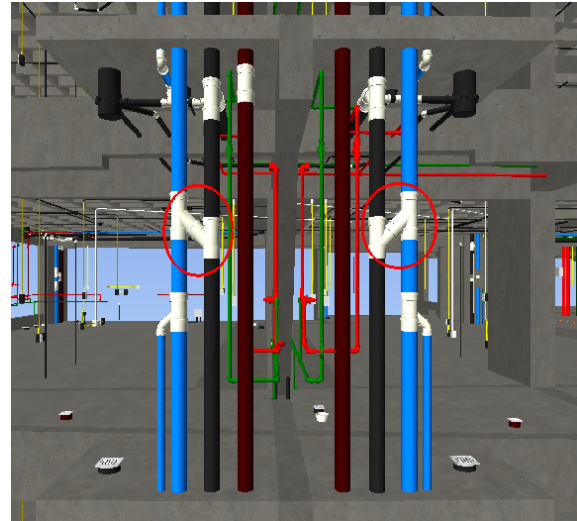


Figure 2: Needed distance correction between ventilation and sanitary pipes.

Architecture and structure's 3D models were created on stage 1. On stage 2, facilities' model was made and the constructability analysis was elaborated through a 3D coordination model that contained all designs, and a report was produced with all identified RFI. The designing teams performed the designs' reviews and released new versions. From this point stage 3 started, in which virtual construction team examined the newest designs' versions in order to verify if the pointed problems were solved or not. In this stage, an approach between designers and virtual construction team occurred pursuing validation of design's information and resolution of most RFIs. After modelling the most recent designs' versions, a final report was released to a construction/incorporation company. This report brought all unattended RFI and/or new questions that emerged from solutions adopted.

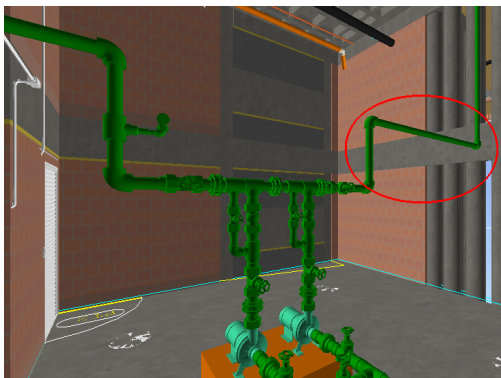
This study adopted RFI's classification in six analyzed categories: design correction, design omission; validation of information, design modification, divergence of information and design verification. Table 1 presents the definition of each classification and demonstrates practical evidence identified by the coordination model analysis.

Understanding these classifications associated with evidence as they happen can contribute so that virtual construction teams may have a referential or a problem category checklist on which they can look up, as well as it may serve as a reference so plumbing system design teams would be able to avoid their occurrence, specially BIM-based design teams.

Figure 2 shows a case of correction, which specified distance between ventilation and sanitary pipes (blue and black, respectively) that do not permit connection execu-

Table 1: RFI classification.

RFI Types	Description	Few examples
Design Correction	Problems associated with presented solution execution or version incompatibility.	It was not possible to connect relief ventilation 10 th floor suite WC. Pluvial plumbing design with 1,42 m exit height below curb when it should be at best 0,10 m to make possible gutter flowage.
Design Omission	Absence of specific design for some areas.	SS2 floor's design did not calculate drainage. Provide hydraulic designs for pool, bodies of water and founts.
Validation of Information	In low complexity cases, when design is partially neglectful about plumbing's route, virtual construction team suggests a solution to designer's validation.	Validate hydraulic supply to garden's faucet, unindicated in ground floor's design. Pathway of discharge piping from drainage well partially omitted.
Design Modification	Solution adopted is not wrong, but analysis shows an opportunity of a better solution in order to avoid undesired situations.	Modify PW route supply from lookout WC Drainage plumbing has its initial point in pool area, causing insufficient height ($h = 1,59$ m) for parking area.
Diversion of Information	Design mistake associated with lack of attention where, two or more different drawings (plan, vertical scheme and isometric drawing) present different information.	Confirm type of plumbing: floor plan and detail plan indicate different types. Floor plan a construction detail has different information about utilized material
Design Verification	Low complexity issues where design can be mistaken or not. Opportunity for design enhancement.	Verify ventilation need for siphoned cash at sauna's shower. Verify possibility of changing inclination from 1% to 0, 5%.

**Figure 3:** Difference of diameter information between plans and isometric detail drawings.

tion between them using a “Y” connector. Minimal distance verified by virtual construction in order to support execution was 330 mm between 100 mm plumbing axes.

Figure 3 demonstrates divergence of information where highlighted plumbing has a different specification on floor plan drawings and isometric detail.

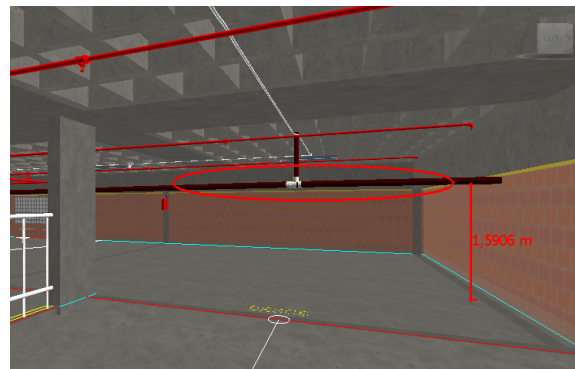
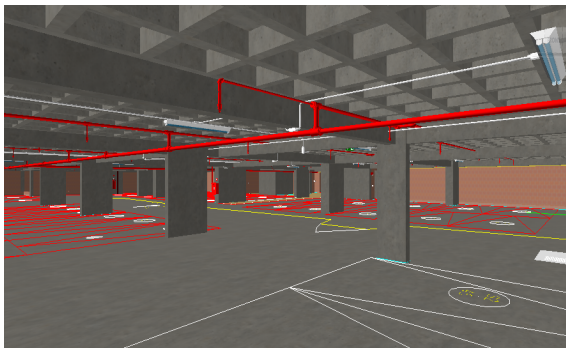
**Figure 4:** Insufficient height causing necessary modification.

Figure 4 shows a design modification where the beginning of the pipe is located in the lower slab because the bottom of pool is placed above the underground parking lots. Because of this and mandatory slopes, every extension was virtually built with insufficient height for vehicles to maneuver. Based on that, the design team analyzed the context and proposed a new route of facilities aimed

Table 2: How to identify and avoid MEPF Systems problems.

RFI Types	How to avoid/identify
Design Correction	Verify connection feasibility between sanitary and ventilation plumbing; Verify plumbing vertical alignment passing through floors from roof; Verify coincidence between rainwater output level and gutter level; Verify coincidence between sanitary plumbing output level (considering mandatory inclinations) with sewage systems.
Divergence of Information	Verify drawing differences (plan, vertical scheme and isometric detail) analyzing route, specified materials and dimensions (diameter);
Design Modification	Verify height of plumbing considering mandatory slopes, level of associated floors, internal height and quote and lining existence;
Design Omissions	Verify/request hydraulic design for pool, water body and fountains; Verify/request drainage design for garden, covered slabs and undergrounds;
Validation of Information	Verify feasibility of isometric details, layout and supply network (hydraulic derivation); Verify existence of level differences in drawings;
Design Verification	Verify if, considering mandatory slopes, they can be reduced (change 1% to 0, 5%); Verify ventilation need in sanitary plumbing and siphoned cash

**Figure 5:** Omitted underground drainage.**Figure 6:** Needed validation for path of discharge pipes.

at enabling the use of the underground space and avoid inconvenience to the users.

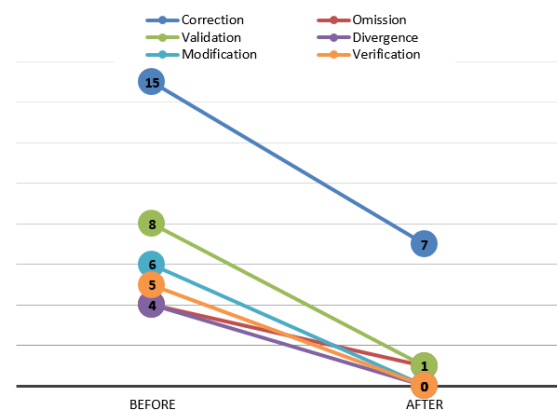
**Figure 7:** RFI classified reduction in each stage.

Figure 5 demonstrates design omission that has been virtual and completely built and the existence of facility for floor drainage was not detected. This is a case of a simple mistake, easily detectable if the design checklists are considered, then preventing it from becoming a RFI on future designs.

Figure 6 shows an example of design validation RFI type, this figure shows how the path of discharge pipes was built virtually from VDC team's decision on a partially undefined way in designs.

In this case study, all items related as verification, variance and modification were eliminated, and items related as omission and validation were reduced to only 1 occurrence. Designers considered all listed RFIs as design corrections, but this caused new conflicts after design modifications. Thus, commitment with design improvement did

not lead them to perfection, but delivered a small number of RFI, already identified, to be analyzed and resolved by the construction team. Figure 7 shows substantial RFI reduction in each category.

The identification of conflicts is a reactive approach while avoiding conflict is proactive, thus, we have to develop ways to improve design process in a way to reduce occurrence of future conflicts [20]. Table 2 summarizes recommendations to identify and avoid these RFI types in plumbing system design process or during virtual construction.

6 Conclusion

The results demonstrated VDC's contribution for improvement of plumbing system designs. These results are valid to use as a guide in adopting a proactive approach for identifying conflicts, according to the proposed by Tommelein and Gholami (2012), although each project has its unique characteristics. In many cases, 3D construction model reveals execution impediments that are not possible to visualize in 2D drawings. 3D environment uses real sized pieces, tubes and equipment, obeying necessities slopes and space and structure limitations. Requests for information are financially valuable to the constructor. RFIs in this specific case can contribute for improvement of conception, production and managing processes of new water/sanitary facility designs as long as they are considered during the integrated design process in which participants are committed to eliminate future RFIs, making the whole process cleaner.

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