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Facilitating the BIM coordinator and empowering the suppliers with automated data compliance checking

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ABSTRACT: In projects with Building Information Modelling (BIM), the collaboration among the various actors is a very intricate and intensive process. The various suppliers and engineers provide their input in Industry Foundation Classes (IFC), which in turn is used for design coordination. However, the IFCs have to undergo an intermediate checking process to ensure compliance with various client-set and technical requirements. The paper focuses on the potential of (semi-)automatic IFC compliance checks and discusses a relevant recent initiative in the Netherlands, according to which several IFC compliance criteria were agreed among 14 contractors. This study aims to unravel the changes induced by this development not only as to the IFC compliance checks, but also as to potentially balancing the roles between the BIM coordinator and the suppliers.

1 INTRODUCTION

The use of Building Information Modelling (BIM) technology in Design and Construction has proliferated the last years. The benefits of BIM have contributed to the increasing number of adopters in Architectural, Engineering and Construction (AEC) industry. The information exchange among the various disciplines has been made possible via Industry Foundation Classes (IFC), which is the main open data standard (Berlo et al., 2015). Although it is argued that IFC still faces semantic challenges (Amor, 2015), particularly due to its evolving structure, it offers satisfactory and consistent information flows.

Currently, BIM implementation has been synonymous with IFC exchange among the various multidisciplinary actors. Recently, the periodic – usually weekly – control sessions of IFC have become increasingly important and complex. These periodic controls involve various actors of the AEC supply chain, such as engineers, consultants and suppliers, who generate their own version of the building project. An emerging role in this process is the role of the BIM coordinator, who is in charge of the process of IFC exchange and federation of the various aspects of BIM models from the different disciplines respectively, under the concept of ‘aspect models’ (Berlo et al., 2012). However, this process is continuously undergoing change, as there are many efforts taken to automate the process of receiving, checking and federating the IFC aspect models. Subsequently, such changes induce transformations in the roles of the BIM coordinator and the involved suppliers.

The contribution of this paper is to provide new insights into the process of automated data compliance checking and the respective changes in the roles of the BIM coordinator and the suppliers. The study draws data and presents recent efforts from both ‘top down’ mandates and ‘ground-up’ industry initiatives for compliance checking criteria to ensure that every actor could always access, handle and reuse information in a consistent manner.

The paper is organised as follows. First, the background, related work and research gap pertinent to automated data (IFC) compliance checks and the associated emerging roles are presented. Second, the selected methodology to present and analyse the data is described. Then, the data from the semi-automatic improvements to periodic controls are presented, and their inter-organisational implications are discussed. Finally, the paper concludes with a summary of the main benefits and repercussions of the phenomenon under study and sets points for future research.

2 BACKGROUND, RELATED WORK AND RESEARCH GAP

2.1 *Industry Foundation Classes (IFC)*

Previous research has underlined the potential of BIM for reliable collaboration through the combination of IFC and model-checking software, such as Solibri Model Checker and Tekla BIMSight. The

IFC is currently the main open data standard for practitioners in AEC. The IFC was initially introduced in the 1990s from an international consortium of software vendors and researchers, who formed the International Alliance for Interoperability (IAI), now called buildingSMART. The development of the IFCs has undergone various versions and additions the past decades, which have become a burden for the software developers and vendors (Amor, 2015). Despite those challenges, the IFCs provide freedom to the end-users to use the proprietary BIM authoring application of their preference to design their part.

Accordingly, as the most readily used open data structure, the IFC model has continued gaining traction among the AEC professionals, and in particular in combination with model checking software. Solibri Model Checker, BIMserver.org, and Tekla BIMSight are popular model checking applications that rely heavily on the use of IFC data. Most of the model-checking applications support the data exchange about specific issues that arise in a project in the BIM Collaboration Format (BCF). By aggregating and viewing simultaneously the IFC data from various disciplines in a project, e.g. engineers and suppliers, these applications report on coordination issues among the input of the various involved actors, using built-in or custom-made checking rules.

2.2 *Collaborative Engineering with IFC*

Various experiments with IFC and model checking software have been conducted the last years. These efforts were triggered by the curiosity to understand and explain the collaboration with BIM (Berlo et al., 2012). These research efforts have taught us that the dogma of a 'central BIM repository' itself does not bring (much) added value in a team collaboration. Unfortunately, the misconception that when everyone uses the same data structure, collaboration will immediately happen still exists. This idea probably adds to the confusion about how to collaborate efficiently and effectively with BIM, given that it could essentially be defined as '*a multifunctional set of instrumentalities for specific purposes that will increasingly be integrated, but to what extent is an open question'* (Miettinen and Paavola, 2014). Thus, the processes and functions to collaborate within the concept of BIM are still under development and rely heavily on the technological advancements.

In the Netherlands, there are numerous studies on the emerging BIM-based collaboration processes via IFC and model-checking software, following the concept of 'reference models' (Berlo et al., 2012, Berlo et al., 2015). After experimenting with the use of BIM in a central data repository it was concluded that the concept of exchanging 'reference models' (or 'aspect models') was a stable way to exchange data produced by the various disciplines, in their preferred BIM software, in an asynchronous manner, e.g. weekly (Berlo et al., 2012). Following-up experiments in the Netherlands further confirmed the use of IFC and model checking software as a common engineering practice in a BIM environment and underscored the challenge of BIM to align with the existing project phases (Berlo et al., 2015). From the previous studies, one could conclude that the periodic controls of the IFCs consist of three interconnected steps:

- Compliance check with the requirements (data level);
- Aggregation of the IFC files (information and/or data level);
- Coordination of the design (information level).

2.3 *Data compliance checks with IFC*

To perform high-quality coordination and model checking, the data has to be of high quality as well. The data requirements are usually stored in a BIM Protocol or BIM Execution plan. In the recent years, a commonly accepted standard has emerged for IFC data requirements. These requirements are heavily influenced by the Dutch Rijksvastgoedbedrijf BIM norm. Rijksvastgoedbedrijf (2012) started mandating IFC data requirements with a norm that in turn seemed to have been influenced by the Norwegian equivalent authority of Rijksvastgoedbedrijf, called Statsbygg, which previously published similar BIM requirements (Statsbygg, 2011).

The IFC data requirements have formed a baseline for checking the IFC data requirements in the industry for a long time. In the recent years, the industry has extended and additionally fine-tuned the original IFC requirements set by the Rijksvastgoedbedrijf. From anecdotal sources and informal interviews with practitioners, the following set of requirements has now emerged as a common requirement set used by most AEC contractors:

- There should be only one IfcProject object per file (no more, no less);
- There should be only one IfcSite object per file;
- All objects should be linked to an IfcBuildingStorey object;
- There should be at least one IfcBuilding object in the dataset;
- There should be at least one IfcBuildingStorey in the dataset;
- The naming of the building storeys should be consistent and in order, i.e. floor-numbers;
- The length unit should be millimeters;
- The area unit should be square meters;
- The volume unit should be cubic meters;
- The objects should be 'close' to the origin point (0,0,0) of the dataset;
- Objects found across multiple 'aspect/reference models' should have the same position and orientation point;

- There should be no intersections in the individual 'aspect models';
- There should be no duplicate objects in the entire dataset.

The clients' firms have mandated the same requirements and further added the following requests:

- The dataset should have the true North set;
- The site elevation should be set;
- The site latitude and longitude coordinates should be set;
- The site cadaster ID should be available.

Most of the above requirements come from a combination of the Statsbygg requirements, the Rijksvastgoedbedrijf BIM norm, and practical insights. On April 2016, a new initiative in the Netherlands reached an agreement about the criteria for the compliance check to ensure that every party could always access, handle and reuse information uniformly. This initiative was initiated by BuildingSMART Benelux and was executed with a core team of fourteen large and medium size Dutch contractors. This action could simplify, improve and reduce the conflicts during the periodic controls of the IFC within and across construction projects. The goal of this initiative, called 'Information Delivery Specification' was to align the BIM data requirements that contractors mandate to their project partners. The agreed criteria for the compliance check are (National BIM Guidelines, 2016):

1 Uniform file naming of the various reference models from the difference disciplines;
2 Same position and orientation point;
3 Consistent naming and appending of the various building levels;
4 Correct generation and structure of IFC objects;
5 Correct names in the IFC entities;
6 Consistent classification of the objects under the NL/SfB system;
7 Correct attribution of the materials' description;
8 Elimination of duplicated entities and internal clashes per aspect of the federated model.

From the above, there is an apparently extended overlap between the 'Information Delivery Specification' and the requirements previously described at the beginning of this sub-section, derived from literature and anecdotal evidence from interviews.

2.4 *Emerging functions during collaborative engineering with IFC*

The above means, i.e. IFC, and processes, i.e. periodic controls of the IFC, affect the functions and the responsibilities of the various involved professionals during the information exchange in a BIM environment. The process of the – usually weekly – periodic controls of the IFC from the various disciplines is governed by BIM coordinator, who is responsible for the check, aggregation, and coordination of the data and information. However, given that the concept of collaborating in a BIM environment is currently under development, there is a lot of ambiguity about the appropriate functions to support a BIM project.

Gathercole and Thurairajah (2014) provided evidence of this ambiguity by mapping how the various BIM functions are described in BIM-related job advertisements in the United Kingdom (UK). From their analysis, three main BIM-related roles emerged: 'BIM manager', 'BIM coordinator' and 'BIM technician'. Whereas the BIM managers had mostly BIM-related project administrative functions and the BIM technician had mostly modeling duties, the BIM coordinator's role was inconclusive and assumed responsibilities from both administrative and modeling domains (Gathercole and Thurairajah, 2014). Thus, there is a gap of knowledge in the function and responsibilities of the BIM coordinator.

Another aspect to be considered about the BIM-related functions is apart from the technical and administrative skills, the soft competences that are mobilised in a multi-disciplinary setting. Davies et al. (2015) underscored that skills such as communication, conflict management, negotiation, teamwork, and leadership were also deemed essential for a BIM environment. This paper distinguishes the firm-based BIM manager who is responsible for BIM adoption in a firm including BIM strategy and training, from the project-based BIM coordinator, who is responsible for the periodic IFC controls and operational issues, and focuses only on the latter.

As presented through the various efforts to coordinate the periodic IFC controls across firms, there are still opportunities to further improve these controls and particularly regarding the compliance check to the requirements. The changes and improvements in IFC compliance checking could probably lead to a reconsideration of the function and the role of not only the BIM coordinator but also the various other parties involved in the periodic controls with IFC, i.e. the engineers and suppliers. Thus, there is a lack of understanding about the changes that the semi-automated IFC compliance checking entails for the (a) periodic IFC controls and (b) the function of the BIM coordinator and the various involved actors, such as engineers and suppliers. The study sets out to explore the following research question: *How does the pre-processed automated IFC compliance checking affect the process and the functions required for the periodic controls of IFC?*

3 RESEARCH APPROACH

3.1 *Setting of the study*

The Netherlands has been selected for this study because it has been displaying a variety of examples on self-regulation in the AEC market. Also, this study could be considered a follow-up of other relevant previous studies about collaborative engineering with IFC in the Netherlands, e.g. Berlo et al. (2012) and Berlo et al. (2015). Moreover, compared to other countries who are usually described as forerunners in BIM adoption, in the Netherlands there is a balanced distribution of mandatory and suggestive publicly available publications such as guides, protocols, and mandates (Kassem et al., 2015). The Dutch BIM policy-making authorities have been so far reluctant to publish mandatory documents and have been mainly relied on a ‘ground-up’ rather than ‘bottom-up’ BIM diffusion approaches. After all, Winch (2002:25) has described the Dutch construction industry as a *Corporatist type System* according to which, the “social partners” are more keen to negotiate and coordinate to control the market. Accordingly, the Dutch AEC firms are proactive in adopting new technologies with a consensus-seeking culture.

3.2 *Hypothesis*

A common iteration in the Dutch industry between contractors and suppliers is described by Berlo et al. (2015) and shown in the top part of Figure 1 (a). The suppliers send their design input as IFC data to the contractor during the week. The contractor checks and aggregates the data (usually) on a Friday and performs several checks of the model as part of their project coordination role.

Unfortunately, not all IFC requirements are met by suppliers, according to testimonials from practice. This in turn induces a great burden on the BIM coordinator, who would have to rectify the situation, during the coordination sessions. The BIM Coordinator has less time available to spend on actual project coordination among the various disciplines, because he would spend much time on fixing the non-compliant models instead, given that the sub-process between the submission of the data and the compliance check behaves as a bottleneck. The research hypothesis is formed as follows:

The BIM Coordinator (project coordinator) could spend more valuable time on actual coordination tasks when the data from the suppliers is meeting the requirements.

The hypothesis would be tested by comparing how the checking tasks could be reduced in a new process, shown at the lower part of Figure 1 (b). The data from the suppliers that is usually sent via e-mail or put in a shared folder, e.g. Sharepoint, Dropbox, and many others, could be instead uploaded to an online model server. During the uploading of the data, the dataset is checked against basic requirements. When the data does not meet the requirements, the upload function is rejected by the server. This process ensures that only qualified data reaches the BIM coordinator. The suppliers are ‘obliged’ to improve and send valid data for the coordination.

3.3 *Research methods*

The main research method was an exploratory case study, using reports on IFC data from three projects in the Netherlands. Out of the fourteen contractors that participated in the previous BuildingSMART in-

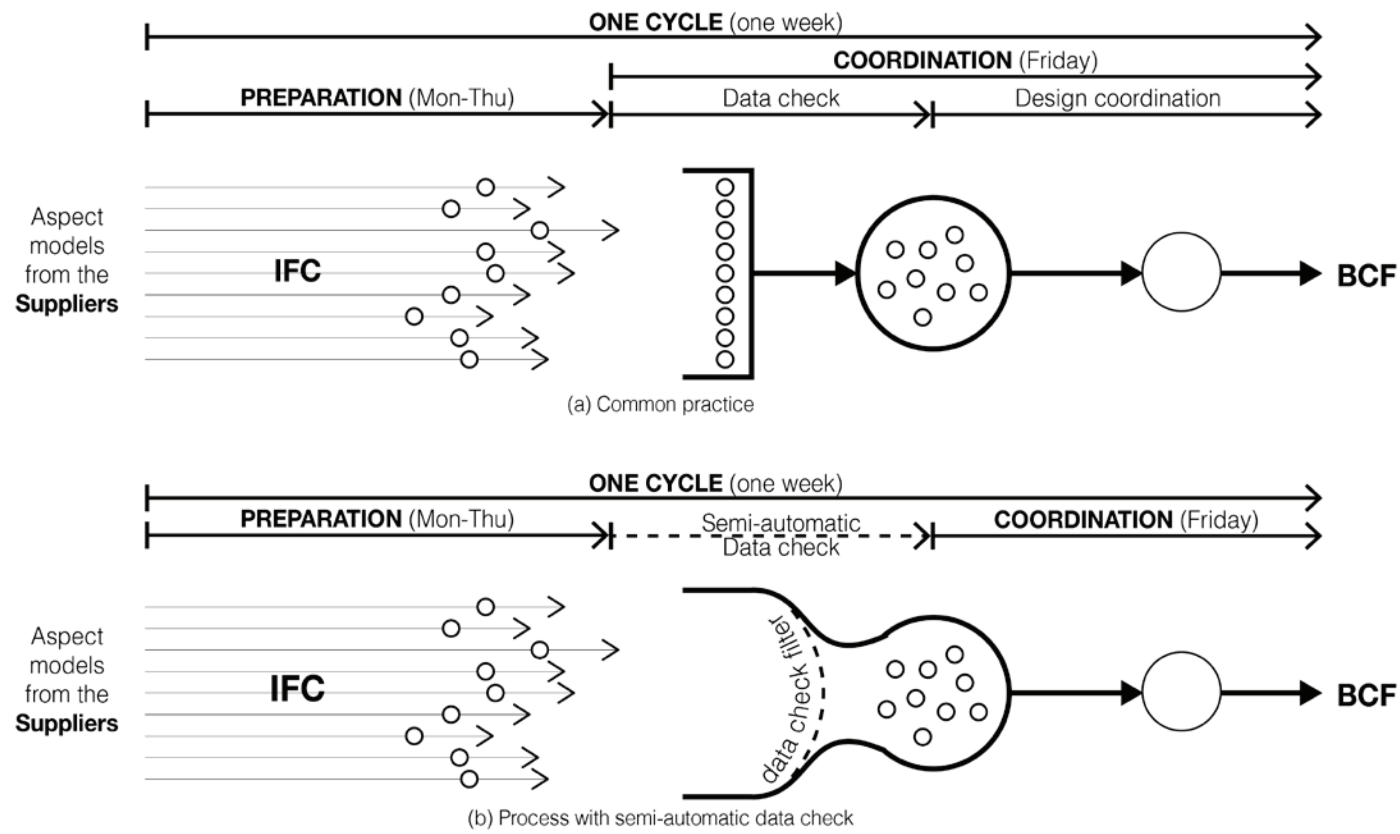

Figure 1: (a) The common practice of coordinating IFC data where the data are checked on compliance by the BIM coordinator and (b) the new process featuring semi-automatic data checks.

itiative, three were selected by their long-lasting experience with using an (online) checking platform. The three studied projects used recent data, not older than a year. The IFC and model-checking processes were described, analysed and evaluated as to following aspects:

- The rules used for checking the BIM models;
- The BIM protocols as ground for setting requirements for the engineers and suppliers;
- The tasks and the role of the BIM coordinator;
- The software infrastructure for the controls;
- The BIM readiness and capability of the contractors, designers, engineers, and suppliers.

This study analysed several datasets from suppliers and checked them against the requirements in an automated manner. The following checks were performed:

1 Is there one (and only one) IfcProject object?
2 Is there one (and only one) IfcSite object?
3 Are all objects linked to an IfcBuildingStorey object?
4 Is there at least one IfcBuilding object?
5 Is there at least one IfcBuildingStorey?
6 Is the naming of the building storeys in order (numbers)?
7 Is the length unit in millimeters?
8 Is the area unit in square meters?
9 Is the volume unit in cubic meters?
10 Does the dataset have the true North set?
11 Is the site elevation set?
12 Are the site latitude and longitude coordinates set?
13 Is the site cadaster ID available?

For one case (case A) also additional checks were performed using the semi-automated approach:

- Are the objects ‘close’ to the origin point (0,0,0) of the dataset?
- Are all objects from multiple ‘aspect models’ on the same position and origin point?
- Are there no intersections in the aspect models?
- Are there no duplicate objects in the entire dataset?

4 DATA ANALYSIS

The study compared the IFC periodic controls of three cases. The cases featured the common practice of iterative collaboration based on IFC, during which once a week, the segregate models from the various disciplines were checked, aggregated and coordinated via model-checking software by the BIM coordinator as described by Berlo et al. (2015). The cases followed the experimental process for automated IFC compliance checks. The various involved suppliers used an online platform to upload and automatically check their IFCs mid-week. In total 88 files from suppliers were analysed in the three cases (A, B, and C). The results are shown in Table 1. The rows contain the various suppliers per case, and the columns contain the different checks performed in the datasets. The checks are compared using the symbols “v” and “-” when the file was or not compliant respectively. Three requirements were met in all the files: only one IfcProject object (requirement 1); at least one IfcBuilding (requirement 4) and the length unit (requirement 7). Therefore, these results are not included in Table 1.

Table 1. Results from the data compliance checks per case.

Supplier per case	No. of IFC files	Check #2*	Check #3	Check #5	Check #6	Check #8	Check #9	Check #10	Check #11	Check #12	Check #13
A1	1	-	-	-	v	v	v	-	-	-	-
A2	1	v	-	v	-	v	v	-	-	-	-
A3	3	-	-	-	v	v	v	-	-	-	-
A4	4	v	-	v	v	v	v	-	-	-	-
A5	1	v	v	v	v	v	v	v	v	v	-
A6	1	v	v	v	-	v	v	v	v	v	-
A7	1	v	-	v	-	v	v	-	v	-	-
A8	3	v	-	v	-	v	v	-	v	-	-
A9	13	v	v	v	-	v	v	v	v	v	-
A10	1	v	-	v	-	v	v	v	v	v	-
A11	1	v	v	v	-	v	v	-	v	-	-
A12	4	v	-	-	v	v	v	-	v	-	-
A13	4	v	-	v	-	-	v	-	-	-	-
A14	11	v	-	v	v	-	v	-	-	-	-
B1	1	v	v	v	-	-	-	v	v	v	-
B2	2	v	v	v	v	v	v	v	v	v	-
B3	1	v	v	v	-	v	v	-	v	-	-
B4	1	v	v	v	v	-	-	v	v	v	-
B5	1	v	v	v	v	-	-	-	v	v	-
B6	1	v	-	-	v	v	v	-	v	-	-
B7	1	v	v	v	-	-	-	v	v	v	-
B8	1	v	-	v	-	-	-	-	-	-	-
B9	4	-	-	-	v	v	v	-	-	-	-
B10	1	v	v	v	-	-	-	v	v	v	-
B11	3	v	-	v	-	v	v	-	v	-	-
B12	1	v	-	v	-	v	v	-	v	-	-
B13	1	v	v	v	-	v	v	-	v	-	-
B14	1	v	-	v	-	-	-	v	v	v	-
C1	3	-	-	-	v	v	v	-	-	-	-
C2	3	-	-	v	-	v	v	-	-	-	-
C3	3	-	-	-	v	v	v	-	-	-	-
C4	1	v	-	v	-	v	v	-	v	-	-
C5	3	v	v	v	-	v	v	v	v	v	-
C6	4	v	-	v	-	v	v	v	v	v	-
C7	2	v	v	v	-	v	v	v	v	v	-
Sum	88	29	14	28	13	26	28	13	24	14	0
%	-	83	40	80	37	74	80	37	69	40	0

*The checks’ numbers refer to the numbered list in section 3.3.

For case A, an extra semi-automated analysis was conducted using four additional requirements. These analyses could also be supported by the automated proposed process, however, to gain more insight into the actual issues and challenges arising, Solibri was used instead. Table 2 presents the data from these additional checks. Again, the checks are compared using the symbols “v” and “-” when the file was or not compliant respectively. Also, where indicated, the total number of errors is calculated accordingly.

Table 2: Additional criteria check for the IFC files of Case A.

No. IFC files	Origin point	Intersections	Errors intersecting components	Duplicates	Errors duplicate components
26	v	v	N/A	v	N/A
1	v	-	16	-	1
1	v	-	16	v	N/A
1	v	-	56	v	N/A
1	v	-	208	-	10
1	v	-	136	-	6
1	v	-	121	-	6
1	v	-	103	-	5
1	v	-	6	v	N/A
1	v	-	N/A	v	N/A
1	v	-	1039	v	N/A
1	v	-	38	-	9
1	v	-	4	-	10
1	v	-	36	-	15
1	v	-	429	-	5
1	v	-	3	v	N/A
1	v	-	7	v	N/A
1	v	-	1	v	N/A
1	v	-	395	-	11
1	v	-	178	-	15
1	v	-	79	v	N/A
1	v	-	68	-	2
1	v	-	16	v	N/A
1	v	-	6	v	N/A
(Sum:) 49	100%	53%	-	76%	-

The checks that were performed focus on the geometric compliance of data. All 49 IFC files of the case A were analysed. All files were close to the origin point. 53% of the files had internal clashes. These are clashes in the individual files, not in the coordination among the various disciplines’ input. The BIM/project coordinator would come across these internal clashes during the coordination sessions and would turn his attention away of the actual design coordination of the project. When clashes were found, the number of clashes (intersections) is listed. Only 76% of the files did not have duplicate objects. The number of duplicate objects per file is also shown in Table 2. However, it strongly depends on the type of coordination (and the phase of the project) if the work from the BIM/project coordinator is affected by these duplicate objects.

The compliance overall percentage of the cases is:

- Case A: 64%
- Case B: 65%
- Case C: 64%

These numbers are quite similar. This is due to the high overlap of requirements that are met, e.g. of the 1st requirement about having only one ifcProject, and not met, e.g. of the 13th requirement about the cadaster information (see again Table 1).

Only two IFC files completely met the requirements: one in case A and one in case B. When we do not take the requirements 10 to 13 into account still only two models met 100% of the requirements (1 in case A and 1 in B). The average percentages of compliance, for only requirements 1 to 9, and the standard deviation, are shown in Figure 2.

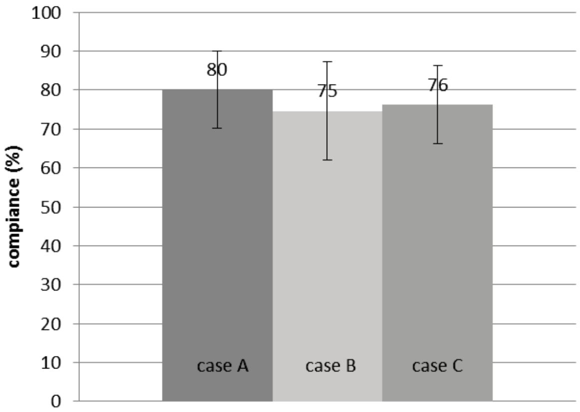

Figure 2: average compliance to the requirements per case (and standard deviation).

5 DISCUSSION

5.1 *Inter-organisational implications*

After discussing and validating the research findings with the case participants, it was concluded that the automated compliance-checking process initially carries inter-organisational implications for the two main categories of project actors, i.e. the suppliers and the BIM coordinators, and afterwards, technical repercussions about the data compliance checks. Concerning the inter-organisational implications, the workload of the BIM coordinator and the suppliers was interdependent. The IFCs that were properly checked and prepared by the suppliers did not need additional coordination and communication back to the BIM coordinator to the suppliers.

First, the various engineers and suppliers were able to check beforehand their data for compliance with the requirements of the BIM protocols, without waiting for the approval of the BIM coordinator during the periodic controls. The suppliers were again responsible for the (data) compliance of their work to the requirements, as it was originally in traditional non-BIM-based projects. Such increased responsibility of the suppliers corroborates with the discussions of Nederveen et al. (2010) that with integrated design process across all tiers, the suppliers would assume a more dominant role in the design and thus, the construction project design process would be more ‘ground-up.'

Second, the project-based BIM coordinator was able to evaluate the information provided by the various partners only as to its technical and engineering feasibility and not as to the syntactical conformance to the rules of the BIM protocol. The BIM coordinator’s role became less related to BIM knowledge and more related to their domain expertise, e.g. architecture, engineering or quantity surveying. Simultaneously, the BIM coordinators would have the room to develop more “soft” capabilities from collaborating with the various partners, which could, in turn, corroborate the discussions of Davies et al. (2015) about an increased demand for additional soft skills to support BIM-based projects. One might claim that the role of the BIM coordinator might also be aligned or concur with the traditional role of the ‘design coordinator,' who used to be responsible for the coordination of the multi-disciplinary input, within the contractors’ firms.

5.2 *Benefits and challenges of the automated data compliance check*

The benefit of this process lies in avoiding the uncertainties of data compliance during the scheduled periodic controls for the alignment of the multi-disciplinary information flows. Looking back to Table 1, there are some interesting observations about the various checks performed, apart from the requirements checks #1, #4, and #7, which are not included in Table 1. For example, it seems difficult to link all the IFC objects to an ifcBuildingStorey (requirement 3), given that only 40% of the suppliers met that requirement.

Regarding the 6th requirement, i.e. the naming convention and numbering of building storeys, surprisingly, it also presented a lot of errors in the automated check. This is probably because no specific naming convention is given, and therefore the automated check can only work partially.

The requirements that are specific to client requests also scored relatively low in the analysis, e.g. the 10th and 13th requirements about the site elevation, true north, the latitude and longitude of the site, and the Cadaster information. Experiments have shown that it is very simple to inherit these properties from the original design model and have the BIMserver add them automatically to the supplier models. These checks are almost never mandated by contractors to the suppliers, through the BIM protocols, and therefore, probably they do not a significant influence on the coordination work of the BIM project coordinator

The requirements for the length, area, and volume unit (7th, 8th and 9th requirement respectively), are quite questionable as to their influence to the work of the BIM coordinator during the coordination. Most software tools recalculate different units during the coordination so the end user might not be hindered by the mismatches in these checks. Subsequently, the most essential requirements for the design coordination seem to be met most of the time.

In all cases and suppliers’ files, the 13th requirement, about cadaster information, was never found compliant using the automated check. To investigate this issue further, some complementary checks with the automated checking tool in other datasets proved that the feature was completely functional.

5.3 *Research limitations and applicability*

Whereas the study reviewed only three cases, the findings could be generalised in other settings. Given that the IFC compliance process is an inseparable process of the federations of the aspect (or reference) models from various suppliers, the above implications and challenges could apply to more projects. At the same time, the presented recent initiative among the fourteen contractors in the Netherlands, who agreed to specific requirements for the IFCs, resembles a ‘middle-out’ BIM diffusion mechanism, previously described by Succar and Kassem (2015), which could in turn influence more firms and disciplines in the Dutch AEC sector.

At the same time, the above findings regarding the transforming roles of the BIM coordinator and the suppliers could be transferred in other countries, where similar checks have been defined ‘top-down’, such as in Norway. Regardless the content of the checks, which could differ from country to country and from client to client, the balance between the BIM coordinator and the contributing actors to the project design, would undoubtedly continue to shift due to the increasingly stricter and probably more sophisticated data compliance checks for the IFCs.

6 CONCLUSIONS AND FUTURE WORK

Some recent developments in the Netherlands included joint agreements on behalf of fourteen contractors for ensuring consistent IFC compliance checks throughout their projects. The impact of this initiative extends not only to these specific contractors, their projects, and the local Dutch AEC market but also aligns with the vision for the use of open data standards in AEC. At the same time, given that these contractors usually have long-term relations and form partnerships with several sub-contractors and suppliers, this initiative and way of establishing joint agreements in the Dutch AEC sector would potentially transform the smaller enterprises in the market. The study identified the conditions to popularise the adoption of automated compliance checks in AEC.

The automated compliance check process presented the potential for a more balanced division of tasks in BIM-based projects, which could not only improve the quality of the building product but also increase the satisfaction among the involved actors. Specifically, the study identified two tendencies across the roles of the involved parties in the exchange and federation of IFC aspect models. On one hand, the study sheds new light on the existing and vividly discussed, role of the BIM coordinator. In particular, it differentiated it to the various BIM-related roles, such as BIM managers and BIM technicians. Simultaneously, by providing evidence from automated data compliance checks, this study highlighted the potential of the BIM coordinator to resume a more design-related rather than a BIM-routinised role. On the other hand, the study highlighted the changing role of the engineers and the suppliers who would assume higher responsibility from checking, preparing, and ensuring that their aspect models would comply with the jointly agreed criteria for IFC-based project delivery.

Whereas this study has shown the potential of online automated compliance checking, there is no clear evidence that the quality of models will improve in the process. Further research would be required across multiple projects to validate this hypothesis. Online checking in this research was done with standardised requirements that were implemented in a custom-made checker tool. To fully reap the benefits of online model checking, a more dynamic approach should be additionally developed. Specific checks per supplier or per type of supplier would then be an option that potentially would contribute to an even higher level of data quality. Several technologies like Model View Definitions, Concept-libraries and BIM Query languages need further research and development to be used in a practical use case as described in this paper.

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REFERENCES

Amor, R. 2015. Analysis of the evolving IFC schema. *In:* Beetz, J., van Berlo, L., Hartmann, T. & Amor, R. (eds.) *CIB W78.* Eindhoven, Netherlands.

Berlo, L., van , Beetz, J., Bos, P., Hendriks, H. & Tongeren, R., van 2012. Collaborative engineering with IFC: new insights and technology. *9th European Conference on Product and Process Modelling, Iceland.*

Berlo, L., van , Derks, G., Pennavaire, C. & Bos, P. 2015. Collaborative Engineering with IFC: common practice in the Netherlands. *In:* Beetz, J., van Berlo, L., Hartmann, T. & Amor, R. (eds.) *Proc. of the 32nd CIB W78 Conference 2015.* Eindhoven, The Netherlands.

Davies, K., McMeel, D. & Wilkinson, S. 2015. Soft skill requirements in a BIM project team. *In:* Beetz, J., van Berlo, L., Hartmann, T. & Amor, R. (eds.) *CIB W78.* Eindhoven, Netherlands.

Gathercole, M. & Thurairajah, N. 2014. The influence of BIM on the responsibilities and skills of a project delivery team. *In:* Amaratunga, D., Richard Haigh, R., Ruddock, L., Keraminiyage, K., Kulatunga, U. & Pathirage, C. (eds.) *International Conference on Construction in a Changing World.* Heritance Kandalama, Sri Lanka.

Guidelines, N. B. 2016. *BIM Basis* [Online]. Available: http://nationaalbimhandboek.nl/onderwerpen/bim-geboden/.

Kassem, M., Succar, B. & Dawood, N. 2015. Building Information Modeling: analyzing noteworthy publications of eight countries using a knowledge content taxonomy. *In:* Issa, R. & Olbina, S. (eds.) *Building Information Modeling: Applications and practices in the AEC industry.* University of Florida: ASCE Press.

Miettinen, R. & Paavola, S. 2014. Beyond the BIM utopia: Approaches to the development and implementation of building information modeling. *Automation in construction,* 43, 84-91.

Nederveen, S., van, Beheshti, R. & Ridder, H., de 2010. Supplier-driven integrated design. *Architectural Engineering and Design Management,* 6, 241-253.

Rijksgebouwendienst. 2012. *Rgd BIM Standard, v. 1.0.1* [Online]. The Hague, The Netherlands: Rijksgebouwendienst. Available: http://www.rijksvastgoedbedrijf.nl/english/documents/publication/2014/07/08/rgd-bim-standard-v1.0.1-en-v1.0_2.

Statsbygg. 2011. *Statsbygg Building Information Modelling Manual Version 1.2 (SBM1.2)* [Online]. Available: http://www.statsbygg.no/Files/publikasjoner/manualer/StatsbyggBIMmanualV1-2Eng2011-10-24.pdf [Accessed 29 April 2016 2016].

Succar, B. & Kassem, M. 2015. Macro-BIM adoption: Conceptual structures. *Automation in Construction,* 57, 64-79.

Winch, G. M. 2002. *Managing construction projects,* Oxford, Blackwell Science Ltd.