An Analysis of 4D-BIM Construction Planning: Advantages, Risks and Challenges

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Abstract –

The rapid growth on the field of project management and building information modelling (BIM) has led not only to the enhancement of architectural/structural design, construction methodology and operation of facilities but also to the generating of the new and exciting applications such as 4D simulations, project scheduling and controlling. 4D planning and scheduling is one of the BIM uses based on the BIM guidelines. Poor quality of construction works, and ineffective scheduling and planning can be significantly mitigated by adopting BIM in early design processes. In this paper, the advantages, possible risks of 4D-BIM construction scheduling, existing and future challenges of 4D planning in the construction industry are discussed. First presented is the primary concept of 4D-BIM simulation with its possible applications and capabilities in construction planning. After that, weaknesses and strengths of generation of 4D simulation/animation of the conventional and prefabricated construction building projects according to the construction schedule are analyzed. The results show that the integration of BIM model in the construction program is essential and ensures greater control over the construction projects. Also, it can be concluded that the automation in 4D-planning needs to be more considered and optimized by programing and formulating of construction planning and geometric model creation. Finally, this study contributes to the construction/project managers to improve their management performance and efficiency of works, also this investigation contributes to identify research gaps and opportunities for future study.

Keywords –

Building information modelling (BIM); 4D simulation; Project scheduling; Construction projects

1 Introduction

Nowadays, construction building projects are becoming much more difficult and complex. Prevalent problems regarding construction building projects arising from weak and insufficient connection between design and construction phases due to inefficient transferring of information and data have been reported. Building Information Modelling (BIM) is a digital presentation of functional and physical characteristics of a project which is regarded as a potential solution to challenges within the design and construction stages. Therefore, BIM is a good technology not only in the design stage, but also in the construction stage, provided it ensures time saving and working effectiveness throughout the project life cycle. To create a 4D model, BIM as a powerful planning and 3D modelling tool need to be complemented with a specific planning software package. The 4D model of a project can be developed to simulate a graphical sequence of execution tasks and construction operations, therewith providing the stockholder with a visual and virtual understanding of the construction process [1-3]. 4D-BIM has been used by designers, engineers and planners to optimize design, and to analyze the buildability of a project plan and manage resource requirements [3]. 4D planning and scheduling are some of the BIM use based on the BIM guidelines. Poor quality of construction works, and ineffectual construction planning can be significantly diminished by adopting BIM in the early design process [1, 4]. It should be noted that the virtual project planning and progress reporting are the scheduling-related themes of the construction stage and some of the intent of these themes are safety planning, cost reporting, and equipment machine control. The utilization of 4D-BIM modelling in line with analyzing the effectiveness of delays on the project schedule and tracking the actual progress of the project schedule improved the construction performance. The onsite construction performance can be enhanced by linking building information models with schedules so as describe the: 1) material handling and site logistics 2) virtual building model 3) site production structures 4) environmental management controls and related equipment [5]. A study presented a BIM-based integrated scheduling approach for detailed scheduling under resource constraint to simplify the automatic generation of the optimum construction schedule for building projects by performing in-depth integration of BIM/project models with process simulation and work break down (WBS) information. The proposed scheduling system can produce schedules for panelized construction. This system facilitates on-site assembly work by lessening human error [2]. The contractors' tender team can use 4D-BIM scheduling in developing executable risk mitigation strategies. In addition to that the advancement of efficient risk mitigation strategies are supported by 4D-BIM tool during the procurement phase of an actual construction project. Using the 4D-BIM tool has some challenges due to the dynamic nature of the procurement phase resulting the 4D model was not an invaluable tool for contractors [6]. A study reported the development of a control method and logistics scheduling for site assembly of Engineer-to-Order (ETO) prefabrication building system using 4D BIM as a mechanism for dealing with the uncertainties in the construction project [7]. 4D-BIM contributes to improve the work-space scheduling and the associated frameworks enable the detection of possible site congestions by utilizing workspace specifications, construction schedule and activities. 4D-BIM tool improves safety planning process by analyzing site-specific temporal and spatial information [8]. Another investigation introduced a framework for automatic scheduling of construction project through automatic data extraction by using BIM. The proposed framework creates a schedule which contains construction tasks, duration and the activity's sequences. The model has some limitations which is related to the scalability and complexity. The model is a simple BIMs with limited details so by increasing its complexity the model requires more time to generate the construction schedule, and finally some practical methods need to be applied to determine the interdependency between activities and associated elements to minimize the use of use input and default settings [9]. An innovative BIM-based management workflow has been suggested which integrates digital programing with BIM to implement cost planning and efficient schedule of building fabric maintenance. In this research Weibull Distribution is utilized to specify the main information about the corrective and preventive maintenance for building fabric components. A case study was conducted for checking the validation of the model and the practicability of the proposed workflow. This study not only reduced the knowledge gap between practical maintenance applications and maintenance theory but also linked the maintenance phase with design and construction phases. The investigation asserted that a lot of manual works related to information flow need to be done such as data gathering, entering details and creation of functions and tables [10].

By considering the development of the abovementioned applications and technologies, this study accomplishes a review of the relevant literature with the following objectives: 1) summarizing the capabilities and applications of integrating BIM/4D-BIM in construction projects; and 2) identifying advantages of integrating BIM/4D-BIM in construction projects; and 3) summarizing the potential risks and challenges in integrating BIM/4D-BIM in construction projects 4) analyzing of previous investigations 5) conducting a case study for validation of results. This paper aims to identify research gaps and opportunities for future study by considering the advantages, risks and challenges of using BIM and 4D-BIM planning in construction projects.

2 The Implication of 4D-BIM in the Construction Projects: Capabilities and Applications

2.1 4D-BIM Capabilities

The increasing utilization of 4D modelling in construction projects emphasizes on chances for using these capabilities in recent digital management system incorporating with role reorganization, workflows and practices providing a tool for onsite monitoring and constructability analysis of construction progress. The 4D-BIM can only be developed by the accretion of three main capabilities as follow, 1) capability is the visualization of space and time relationships of construction project activities, 2) analysis of the construction program to evaluate implementations, and 3) reduction of errors via construction schedule validation to improve the integrity of communications and collaborations between the project team. 4D-BIM capabilities can be dived into two categories: 1) construction scheduling, and 2) site scheduling. Some of the prevalent end points in leveraging 4D-BIM capabilities are exemplified to improve scheduling, monitoring and waste management. Rule-checking method is a 4D-BIM platform with a rule engine which provides a capability to determine effective environmental rules to support a rule-checking method. In this method, a time-space detection would automatically recognise environmental hot-spots and enhance monitoring performance [5]. 4D simulation allows for the investigation of different scenarios to optimize the construction process. The arrival of BIM as a first commercial tool has made this discipline noticeably easier, specifically with the capability to use

BIM to streamline the creation of links between activities and the 3D models. 4D modelling provides some planning capabilities and incorporates the CPM logic into the software [11].

2.2 4D-BIM Applications

4D-BIM is used to identify project clashes by applying the outcomes to the case study in order to assess feasibility of the system and practical applications. The application of BIM technology to task scheduling is an appropriate choice for clarification and organization of the execution scheduling [12]. A communication strategy has been proposed between 4D-BIM and Chronographical scheduling application developed on VBA Excel. The use Chronographical 4D planning and its compatible approaches, not only consider the linearity of team's production and the workspaces, but also make the study of links between activities easier. This modelling simplifies the automation of the 4D-BIM and change management process [11]. 4D-BIM is used to investigate and validate necessary details to incorporate a special type of sensor (ultrawide band localization system) and try to diagnose the right amount of details to capture the movement of equipment, work force and material. In this application, semantic data modelling and data mining have been used. This integration provides a flexible and high-performing pattern recognition methods [13]. A BIM base decision-making framework is proposed to minimise construction waste in design phase and to automate waste analysis by planning the process of work to reduce the material wastes for roof sheathing installation for prefabricated buildings. A hybrid algorithm integrating greedy algorithm and particle swarm is used to optimize material cutting plans for minimising sheathing material waste [14].

Integration of 4D-BIM with as-built photographs using time-laps photos was presented for monitoring of construction progress. Visualization is needed to create an automatic monitoring system, and this could be achievable via creating a 4D-BIM modelling from point cloud images and implementing an image classification for detection of progress and as-scheduled model from BIM. Regarding to this matter a framework is proposed to develop a concept archetype of a hybrid system to demonstrate the capability of processing images of construction site and integration of them with the nD-BIM within a game like VR environment. This framework enables stockholders and construction managers to use an advanced decision-making tool while detecting the inconsistencies in and efficient manner [15]. 4D-BIM is used to illustrate the planning phase to communicate, interact and get the final design approval and construction sequence. For improving the communication of construction planning and sequencing, 4D-BIM is developed to link BIM to the project schedule. in addition to that for generating a cash flow 4D-BIM is linked to the costing data [16]. 4D-BIM is presented as a practical tool for determining construction risks in early stages of construction building projects to take proactive measures in the design and scheduling phase to mitigate site hazards and to plan for safety resource allocations [17, 18].

3 Advantages of Integrating BIM/4D-BIM in Construction Projects

Four case studies demonstrate the time and cost savings realized in using and developing a BIM model for the design, preconstruction, project scheduling and construction phases. As mentioned, some noticeable benefits are realized through the applying of BIM technology in construction projects. The time and cost benefits to the owner were important and the unknown costs that were reduced via visualization, coordination, realisation and detection of clashes and conflicts. Some effective negative issues or risks related to the project planning phase can be controlled or mitigated via using BIM technology such as 1) incomplete documents and design 2) numerous uncoordinated consultants 3) field construction ahead of design 4) owner's frequent design/scop changes and constant design development [19]. One of the most crucial benefits regarding to the integration of BIM within prefabrication is the reduction of disagreement in a final model between manufacturers and designers. Second vital advantage is the simplifying the procurement plan as a united BIM system can facilitate design coordination from the beginning of the project. Early detection of long completion time, exploring design limitations for prefabrications, reducing the fabrication cycle time and coordination errors are also listed as the benefits of integrating BIM in prefabrication industry. The reduction in project duration and the increment in mass customisation are the other advantages of integrating BIM into the design and construction stages of a prefabrication building projects [20]. BIM gives unique opportunities to further harness the performance of prefabricated construction. BIM mitigates the risks of programing in prefabricated construction industry [21].

An study showed that only 7 advantages out of 18 advantages are identified and ranked as important with high value as follow: increase efficiency and productivity in pre-construction and main construction process, determine cost and time related to design changes, rectify clashes in design, enhance and maintain synchronized communication, develop integrated construction planning and scheduling, recognise time-based clashes, track and monitor the progress of project during construction. It should be noted that the benefits are significantly depends on BIM implementation which is driven by some factors the such as personal commitments, mutual trust/respect, early involvement of project team, capability to use BIM technology [22]. 4D environment planning contributes to plan and manage the construction phases including logistics and operations. Also, the 4D-BIM development allows to status, monitor and update the construction progress. 4D-BIM is a practical tool and technology for development of economic and technical documentation such project schedule to be submitted for a construction project bidding. Visualization of work schedule performs a better control and construction management over the different stages of project. Correct distribution of workers, minimising interferences among different construction tasks and preventing unnecessary overlaps into the various construction sectors are the other benefits of using 4D-BIM. 4D modelling increases and modifies the logical-temporal connections between the various tasks which brings a high level of off-site prefabrication and continues improvement of works [23]. Table 1 illustrates a synopsis of 4D-BIM benefits.

Table 1. A summarised list of 4D-BIM advantages

No.	Advantages of 4D-BIM	Sources in Literature
1	Enhancing the project performance	[24, 25]
2	Efficient planning and scheduling	[25, 26]
3	Detailing the project stages	[25, 26]
4	Generating multiple planned scenarios	[25, 27]
5	Being used for project bidding purposes	[25]
6	Enhancing the ability to adapt future plans and network changes	[25, 28]
7	Utilising 4D-BIM in line with VR and mixed reality technologies	[24, 25]
8	Using 4D-BIM in line with 3D point cloud scanning technology	[25, 29]
9	Being a proactive platform for risk detection	[26, 25]
10	Being proactive in directly advising and addressing on solutions for projects issues	[27, 25]

4 Potential Risks of Integrating BIM/4D-BIM in Construction Projects

BIM risks are defined in two categories: contractual and technical. Lack of designation of possession of the BIM data and protection regarding to the copyright laws and other legal issues are known as the first risk. Determining a person to be responsible to enter the BIM data into the model and ensuring its accuracy and consistency is another contractual risk. Cost and schedule are the other dimensions of BIM and the associated contractual and technological responsibilities are becoming an issue. Many contract administrators require subcontractors to present detailed critical path method plans and related work costs prior to start of the construction project. Having an efficient collaboration to share the risks of using BIM between the project participants is one of the most effective way to coupe with these risks [19]. Misunderstanding of BIM as the potential management barrier leads to serious risks such as hindering the remarkable achievement and benefits of BIM in construction industry. Having no mature dispute resolution mechanism increases the risks of BIM implementation. There are some risks related to the costs and training time due to learning curve which justifies the noticeable decrease in staff member's productivity and performance. Some employers are worry about squandering money and time on labor training. In comparison with conventional methodologies and techniques, the use of BIM increases the costs during the design phase which might increase the risk of BIM implementation. BIM impeding profitability in construction building industry is known as a significant risk. Insufficient standard practices and insurance applicable to BIM implementation brings new risks to all project's participants. Lack of a standard form of contract brings uncertainty regarding to the BIM implementation and to dealing with this uncertainty more money and time is needed to be spent [21].

5 Challenges in Integrating BIM/4D-BIM in Construction Projects

The main Adoption and acceptance of the BIM has been much lower than expected due to the main two reasons, managerial and technical. As the technical sake: a well-organized transactional construction process model is needed to omit data interoperability necessities, the requirement need to be identified that the digital design data is computable, and Practical strategies for deliberate exchanges and integration of meaningful information need to be developed between the BIM components. The managerial reason cluster around use and implementation of BIM. Now, there is no an explicit consensus on how to use or implement BIM. As mentioned, a standardise BIM process need to be established to define guidelines for its implementation. On the other hand, finding an appropriate time to include and engage project's participants into BIM process will be a serious challenge for owners [19]. The changes in business practices to support BIM process is the most significant challenge in the prefabrication. Changing CAD technology to BIM needs more investment in BIM software, also hardware and training are other two challenges in prefabrication. BIM requires comprehensive knowledge of construction processes, methods and extensive resources. As mentioned, legal and collaborative issues are known as barrier of using BIM in construction projects since using BIM contrasts to assign the responsibility to each party and to define liability issues between the parties. In addition, applying BIM in prefabrication building projects increases the complexity of the model of intellectual property rights [20]. Difficulty in reengineering the current existing process and adaptation to the BIM process is a challenge. Lack of adaption of BIM tools to the building codes to meet the requirements is another barrier for BIM implementation. Increase workload for modelling, resistance to alterations, negative orientation towards data sharing and collaborative working, lack of a well-stablished workflow, lack of an efficient interactivity, lack of sufficient external stimulus, lack of doing research on BIM implementation, costs of tools and hiring BIM specialists, vague economic benefits, lack of protective legislation for protecting the IP rights and lack of BIM standards are listed as BIM challenges in construction building projects [21].

Some stakeholders believe that 4D-BIM is used as a business tool for marketing purposes and that most are not interested to develop a 4D-BIM model as opposed to a 2D program during construction projects which are frequently changing. Previous studies emphasised that some 4D-BIM approaches are constrained due to lack of a cooperative environment. The behaviour and culture of those who involved in BIM processes need to be changed to accept this technology. Modifying of culture can be difficult for those who have accomplished their works in the same method may find it challenging to adapt and accept. Project team and client experiences to implement 4D-BIM are further barriers to the associated technology and process. The size of the organization or company, resources availability and risks of each projects might be effective to the adaption of 4D-BIM technology. Insufficient knowledge and technical matters are two barriers for adoption of 4D-BIM in safety management [30].

6 Analysis of previous investigations

All The database of the selected papers includes 100 articles (including the above cited studies) published from 2010-2020. 4D-BIM Construction Planning, BIM scheduling, 4D planning, 4D scheduling, 4D Construction Planning, 4D-BIM Construction and BIM are used as the search criteria and key words for the advanced search through ScienceDirect website. According to the database of selected papers, as analysis has been done to find the most occurring keywords. VOSviewer, a source graph and network analysis software has been used for this analysis [31].

The outcome is shown in Figure. 1, showing the high occurrence of some words such as building information modelling, BIM implementation, 4D model, construction process, visualization, schedule and etc in 2 various clusters. The size of each circle represents its weight. The higher weight of an item resulted in the larger circle and label of the item. It is quite obvious that the red cluster is the representative of the fourth dimension of 4D-BIM and the most related keywords to this study. 4D model which is grouped by schedule related cluster has the strong direct and indirect connection with building information modelling, collaboration, BIM implementation, adoption, productivity, analysis, cost and time from the green cluster.

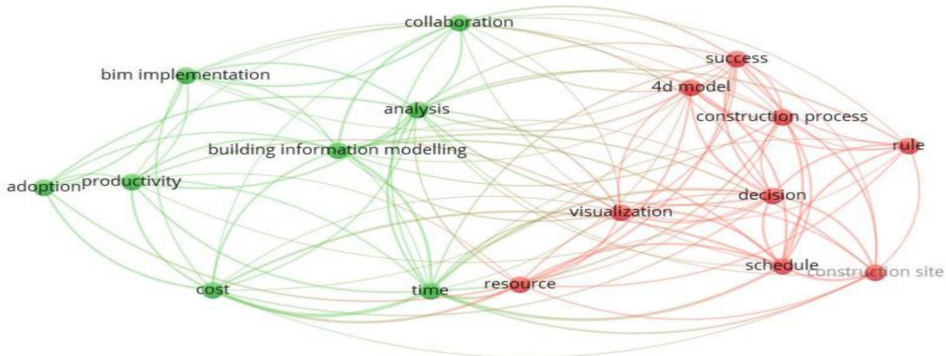

Figure 1. Network representation of keywords re-occurrence in literature

From the above figure, this can be comprehended that 4D modelling as a demanding visualization methodology is the best solution to visualize the construction process and 2D construction schedule. This would be a practical approach to the successful completion of a construction project, saving time/cost and improving performance of the work, resource management and decision-making process. Automation of construction scheduling as a new approach need more collaboration between different parties to be implemented in construction industry. The adoption of this approach has some benefits like improving the performance of site manufacturing and on-site works, increasing the productivity of works and site safety, and challenges such as BIM implementation and rules as these have been mentioned in literature review.

7 Case Study

The Ovolo Hotel is a 6-storey building including 123-guest room, basement and a ground floor common area. This project is also featured SYNC bathroom pods and prefabricated modules which helped to reduce the construction timeline and fast track the project. Program reduced by up to 30% using fast-track prefabricated system in structure. It should be noted that the prefabricated system design, fabrication and on-site installation always come with BIM modelling. Some advantages, risk and challenges of using prefabricated system integrated BIM are mentioned as follow:

7.1 Advantages of prefabricated system and BIM/4D-BIM in Prefabrication

Time saving is an important advantage of the prefabricated system, for instance, once level 4 is installed and bolted, level 1 can be completely stripped out and the level is ready for fitting out. But in the conventional system fitting out is going to be started about 8 levels below the wet deck. As it is illustrated in Figure 2, you can see that façade is already erected and the fitting out period is reduced by 5 working days in average for each level. The financial advantages of the prefabricated system far outweigh than its drawbacks. It should be noted that the cost of pre-construction works in early stages including design and prefabrication cost is a prefabricated project is significantly higher than pre-works cost in a conventional project, but these costs can be offset in construction stages by proper sequencing and coordinating of off-site and on-site works. Prefabricated system eliminates costs of few trades on site such as façade installation costs which is 60% cheaper than façade installation in a conventional system. Prefabricated system requires less labor on site which means less labor cost in construction period. In terms of safety, the prefabricated system does have some risks both horizontal and vertical. Proper sequencing of loading elements and prefabricated modules on to the job reduces safety-related risks on site. Façade is already installed, and this feature creates full protection. In the prefabricated system there is no form work and back propping, so site is always clean which this increases site safety. As it is mentioned, using the prefabricated modules have noticeable advantages by itself, but by providing an effective sequence of construction/loading and visualizing them construction works can be optimized, and site safety and more time/cost saving can be guaranteed. As the prefabricated system is totally a crane-based system, optimization and visualization of construction sequence and loading plan is highly recommended.

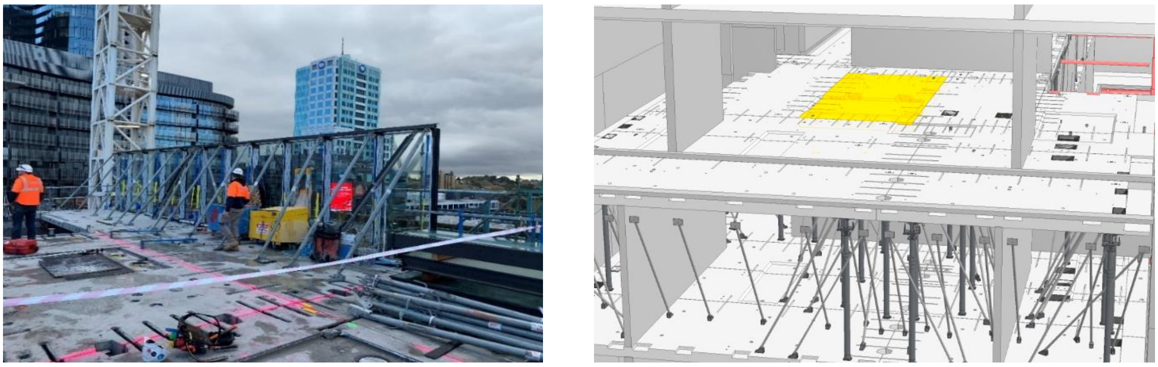

Figure 2. 3D Geometric model of the structure and prefabricated modules

7.2 Challenges/risks of prefabricated system and BIM/4D-BIM in Prefabrication

The main issue in BIM/4D implementation is related to services. Everything related to design such as shop drawings and coordination of shop drawings need to be locked-in early. If all the design related to services is not locked-in on time and early, then technically all penetrations would be wrong due to this fact that all penetrations are casted already in the prefabricated modules. So, any changes need to be captured or any rectifications need to be done early and before pouring concrete off site. If all related design things are not locked-in enough, all hard works such as over layering, penetrations/service coordination go down to drawings which is required to be checked and reviewed by different groups engaged in a project and this is a very time-consuming process. In a conventional system because everything is in-situ, manipulations and making some changes is possible even in last minutes. But as it mentioned above in the prefabricated system pre-works should be well organized because making changes on site is quite impossible after fabrication of modules. In general, design works in a prefabricated project is more complicated than those in conventional project. To make a prefabricated system perfect, effective and to make key decisions early, less duration should be allocated to the design and material procurement in construction program. For this purpose, in addition to the practical experience, high level of technical knowledge is required in different areas such as creating an effective design (3D model), coordinating of trades off site and planning the construction sequence well enough. Because the prefabricated system method is almost new, labors need to be trained and engineers should teach them the new critical path and sequence of work to change their mind set from conventional to the prefabricated system. In summary, from the above-mentioned challenges and risks in both literature and the case study, it can be concluded that using BIM-4D or in another word visualizing the 3D model contributes a lot in clash detection for early rectifications, optimizes the program of the project from design to construction stages and clarifies construction sequence for engineers, coordinators, managers and labors to streamline the construction process and reduce the associated risks and challenges.

8 Conclusion

The study identified some noticeable advantages, risks and challenges of using BIM/4D-BIM in Construction Projects. The research concludes that the adoption of 4D-BIM in construction industry is highly recommended to improve and facilitate off-site and on-site construction works. Shortening and streamlining the procurement, design, prefabrication and construction duration and process in the project schedule are the significant advantages of 4D-BIM integration in the construction industry. Using BIM/4D-BIM can reduce coordination risks, the fabrication cycle time and risks of programing in construction industry. 4D-BIM enables different project teams to be involved early in design and prefabrication/construction process to detect the existing clashes and design errors. For setting a more realistic target, 4D-BIM contributes to visualize the construction and logistic plan. Some serious risks and barriers are acknowledged such as contractual and technical limitations which lead to legal risks and misunderstanding of BIM/4D-BIM. Implementing BIM/4D-BIM requires enough national and international standard practices, comprehensive practical and technical knowledge in the construction industry. Regarding to technical limitations and practical experiences, the automation of the 4D-BIM is required to optimize and simplify the process for better understanding of clients and subcontractors who are not advanced enough to understand the 4D-BIM concept. By automating the process less time and cost are needed to develop the 4D model and less technical knowledge is needed for model implementation which could lead to more future development and adoption of 4D-BIM.

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