Sustainable Infrastructure Design Approach through Integration of Rating Systems and BIM Tools

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Abstract
As the largest sustainability opportunities lie in the infrastructure planning phase, sustainable design can be a critical success factor. Effective green designs use the BIM model as a basis for measuring the various performance analyses. Sustainable infrastructure rating systems are suitable tools for assessing an infrastructure’s environmental performance. Some issues need to be resolved for their integration in the design process. This study propagates a conceptual framework for satisfying the sustainability rating system by introducing BIM with sustainability metric plug in. The adoption allows for what-if scenarios to better support the incorporation of sustainability into design decisions and the assessment of sustainability at different phases of the infrastructure project life cycle. The framework is used to refine designs and ensure that energy-conservation goals are met and to demonstrate compliance with regulatory requirements. A preliminary study is conducted in demonstrating the feasibility of the framework.

Keywords: BIM, sustainability, rating system, infrastructure, sustainable design

1 Introduction

Sustainability in the transport infrastructure industry has attracted great attention. It is rife with propaganda but requires for much greater practical solutions. As the largest sustainability opportunities lie in the planning phase, sustainable design can be a critical success factor.

BIM has been used in buildings for many years, now it is applied across the entire built environment. BIM's information can potentially support early design sustainability analysis. Effective green designs use the BIM model as a basis for measuring the various performance analyses. The major problem appears to be that it is not defined what infrastructure performance knowledge should be in the BIM model.

In theory, BIM and sustainability are a natural fit due to the capacity of BIM to inventory data beneficial for measuring lifecycle costs or performing energy analysis, but in practice, a lot of problems have been arising related to interoperability, regulation, and compliance issues, in addition to software which has been slow to respond to user’s needs.

All of these goals lead to more sustainable solutions for the built environment and are possible to achieve with BIM. The objective of this research is to propose a sustainable design approach for transport infrastructure, focusing on the sustainability rating systems as decision-making criteria along with BIM data. The approach integrates quantitative design data generated from BIM models interacting with performance evaluation in a systematic way. It will give a better insight into the design process and easy access to the reasons behind decision-making moments in the context of integration of BIM data and performance evaluation data in the design stage.

2 Literature review

Standards were developed to express how well buildings perform energetically, such as the U.S. Green Building Council’s Leadership in Energy and Environmental Design (LEED) standards, the UK’s Building Research Establishment Environmental Assessment Method (BREEAM), and other objective and third-party standards. There has been research on the relationship between BIM-based sustainability analyses and the rating systems certification process (Azhar et al., 2010; Cheng & Ma, 2014).

Indicators for assessing the environmental, social and economic performance of infrastructure are vague and transportation-specific sustainability metrics are more difficult to define than buildings. In the building assessment tool BREEAM New Buildings, for instance, thermal comfort is an aspect but this aspect is not relevant for the transport infrastructures. This aspect may not be adopted into the inventory. Therefore, the development of sustainable infrastructure rating systems has been relatively slow for infrastructure works and the transportation sector (McVoy et al., 2010). Most of these rating systems are in their infancy and there are still lack of information about different factors (e.g. carbon footprint) and indicators that are missing at present, but are undergoing pilot implementation testing and revisions with the potential for wider adoption.

El-Said M. Zahran (2013) devised a new three-dimensional (3D) visualization approach for modeled air quality before and after the implementation of potential urban transport schemes. The European project Sustainable Energy management for Underground Stations (SEAM4US) developed an intelligent environmental aware energy management system for underground stations (Casalas et al., 2014). Yigitcanlar & Dur (2010) introduced the Sustainable Infrastructure, Land use, Environment and Transport Model (SILENT). It is a GIS application for urban sustainability indexing and can improve cooperation in decision-making among strategists and planners bent on promoting sustainable development. All these approaches are useful for accessing the sustainability of the infrastructure, however, they fail in the support of a scientific rating criteria.

3 Problems and objectives

3.1 Benefits of designing the transport infrastructure in models

The design phase should be considered as the first stage for achieving sustainability. Many studies have recommended that environmental issues be absorbed into project planning and design and to fully incorporate environmental issues in the planning stage itself (McDonald & Brown, 1995). Incorporating environmental knowledge into planning contributes significantly to sustainable planning. By addressing environmental concerns early in the project development cycle, environmental planning helps to mitigate environmental impacts.

Building codes evolve slowly to reflect worst-case experiences and are applied on a case-by-case basis, whereas computer codes are developed much more rapidly and are debugged by finding and fixing errors. The methods that can be used to predict, to measure and to control the use of energy in dwellings come from simulation tools and standards used in building regulations, both based on physical laws and statistical analysis. The first energy calculation tools integrated within BIM tools are already available in buildings.

Sustainability efforts are mostly based on quantifiable data, whether immediate or long-term, and BIM has the capacity to handle volumes of data. The alignment between BIM and sustainable design is likely to increase into the foreseeable future.

Currently, designers in the transport infrastructure mostly rely on experience and rule-of-thumb judgments. Designers can perform better performance analyses in models. BIM can assist by providing "virtual reality" scenarios to help understand and evaluate the impact of a particular transport infrastructure project on the environment.

The use of performance-based standards, as opposed to prescriptive standards, is likely to increase. All of these trends will put great pressure on developing better metrics for addressing the accuracy of energy and sustainability models.

3.2 Characteristic of the sustainable infrastructure rating system

The scientific community has defined sustainability in numerous ways with both quantitative and qualitative evaluations. While quantitative approaches may provide a more scientific basis for decision-making, a qualitative approach based on norms would likely be better understood and accepted by the general public. Additionally, quantifying sustainability is no simple feat. Each individual facet of sustainability is measured and quantified by different units.

Sustainability is a key indicator for planning transportation projects. Due to current concerns about sustainability and environmental impacts of the construction industry, different methods are being introduced to assess environmental performance. The starting point is the consideration of the sustainability aspects of the entire lifecycle of a certain type of work. Sustainable infrastructure rating systems have been adopted for this purpose. Sustainable infrastructure rating systems are beneficial for establishing a framework for measuring the overall environmental impact of an infrastructure project.

In this research, several sustainable infrastructure rating systems are chosen from USA and Europe for review. The comparison of these sustainable infrastructure rating systems has highlighted several key distinguishing features. The distinguishing features are described below (Atadero, 2014):

1, Use quantitative approaches, qualitative approaches, or both as the basis for allocating points

2, Identify award levels and point thresholds: Projects are assessed using a scoring system. Certain scores are awarded levels of achievement (similar to a LEED Certified, Silver, Gold, and Platinum).

3, Employ self-evaluation or third-party certification: Project assessment (scoring or otherwise) is performed internally by team members involved in the project or externally.

4, Evaluate project in the life cycle: The sustainable infrastructure rating system facilitates consideration of decisions or activities which occur during the conceptual, design, construction, operations and maintenance phase of a project when assessing the sustainability of the project. It applies to a broad range of transportation life-cycle phases or to focus primarily on one or two phases.

5, Choose only relevant criteria to project: The sustainable infrastructure rating system permits a team member(s) to determine whether or not given criteria are relevant to the project and whether they should or should not be used in the assessment, and allow credits/topics that do not apply to a given project to be removed from the total amount of possible points (i.e. customize or tailor the scorecard, as needed)

6, Allocate weights to criteria: The sustainable infrastructure rating systems facilitate the assignment of weights to various criteria or allow the user to apply customized credit weights when assessing the sustainability of the project.

7, Offer a checklist customized to particular types of projects: The sustainable infrastructure rating system organize the credits by phase or topic area, facilitating a checklist customized to differing scenarios. For example, it may have a checklist customized to a rural setting, an urban setting, pavement only jobs, new works, etc.

8, Offer prescriptive measures towards achieving credits: The sustainable infrastructure rating system require certain prerequisites to be met before applicants are eligible to earn points and to promote sustainability, which includes a focus on the decision of what/whether to build, as well as how to build.

9, Offer performance measures towards achieving credits: The sustainable infrastructure rating system identifies and credits certain goals to promote sustainability, but does not prescribe specific decisions or activities to achieve these goals.

10, Ability to compare different project options side by side: The sustainable infrastructure rating system facilitates side by side comparison of whole projects while assessing sustainability.

11, Design awards for the roles of different parties in the project development cycle: The sustainable infrastructure rating system facilitate the adoption of all participants, such as the client, contractor, and designer, etc.

12, Design the tool to allow users to test "what-if" scenarios to better support the incorporation of sustainability into key project planning and design decisions and allow for the assessment of sustainability over time.

13, Allow points to be earned for custom/innovation credits.

Different sustainability rating systems employ different methods for determining or quantifying sustainability, and emphasize different sustainability factors. And it may not necessarily require the use of advance quantitative techniques.

Many of these systems were developed by or for specific agencies with a focus on specific, local environmental needs or context. Several local states and research organizations have set out to develop and implement their own rating systems to measure and quantify the sustainability of their own projects in a regional context. There isn't a current rating system developed and implemented by any national organization.

3.3 The necessity of the integration of BIM and sustainable infrastructure rating system

The credit-weighting approach of assessment techniques is the heart of these approaches. If some key variables are simply "yes" or "no" observation, such guidelines do not create a specific methodology for performing the assessment, but only constitute guidelines and requirements.

The transport infrastructure's sustainability is dependent on several inter-related and inter-dependent factors and these factors are affected by the design decisions made by different players in a construction project.

For sustainability analysis at conceptual design stage, analysis method and criteria should be configured in a way so that it does not rely on detailed design information before that has been generated by the designers when discussed in detail in the paper (Ding 2008). This introduced challenges of sustainability analysis at design stage as follows:

1, in the traditional, non-BIM design workflow, several independent detailed analyses made by expert software required the detailed design information which is obstruct between displays.

2, these independent analyses hinder having a holistic understanding of sustainability issues and presenting a holistic sustainable design solution.

3, limited and fragmented project data exists at early design stage.

The infrastructure sustainability rating system knows about the different aspects of infrastructure sustainability and their relations at systems-level and so can interpret results to support decision making. Key Performance Indicators in the sustainable infrastructure rating system can be used as benchmarks in order to assess and quantify different design choices or other scenarios and even against other buildings or historical performance.

BIM itself is a course of building the database. Creating BIM models is creating the infrastructure digitally in the virtual environment, which needs to be linked with a database of project information. So in theory, any information required for testing "what-if" scenarios to better support the incorporation of sustainability and assessing of sustainability in the scheme is necessary.

There is few research bridging BIM model data and the early design stages in which information about sustainability decision-making factors run throughout the infrastructure lifecycle. This problem can be overcome by the integration of BIM data and sustainable infrastructure rating systems. Figure 1 illustrates the logic addressing the sustainability by using BIM and evaluation methods before establishing the framework.

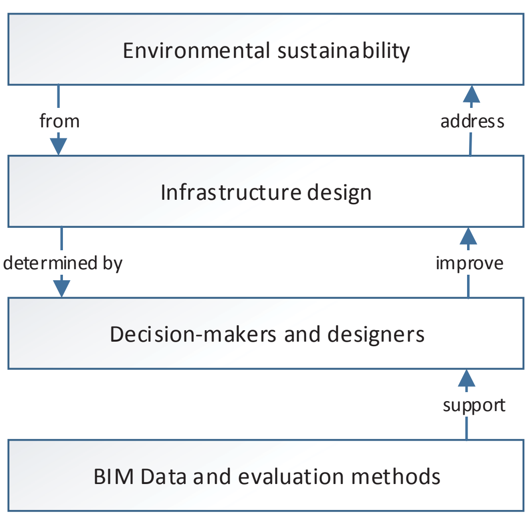

Figure 1 A conceptual framework addressing sustainability by using BIM and evaluation methods

4 Integrating BIM and sustainable infrastructure rating system

4.1 Prototype elements

4.1.1 BIM models

The basic skeleton of the prototype is based on the BIM model of the transport infrastructure. Data stored in well-established BIM model provide enough information and specialized expertise to completing such a computationally complex rating and analysis. When considering a major change, decision-making factors tend to be more related with subjective issues. Performance-wise quantitative data is available only after the design is fully developed. A snapshot of evolving design object is defined without complicated data for subjective sustainability related decision making.

However, computational rating systems may focus entirely on construction equipment, practices and materials. However, they may miss more subtle sustainable ingenuity, such as application of alternative transportation modes to promote less single-occupant vehicular traffic. It means besides BIM models, other kinds of external data are required as supplementary elements.

4.1.2 Integration of sustainable infrastructure rating system

As the second component of the prototype, the rating system is used as design criteria for choosing the best program or the checklist in the best one. Sustainability rating systems are suitable tools for assessing an infrastructure's environmental performance. The existing sustainable infrastructure rating systems have covered almost every aspect of sustainability in the domain of infrastructure. A defined list of indicators cannot make a future proof assessment system. BIM seems a good resource providing needed information. Digital mechanisms of BIM will help enhance its usability to the maximum level.

There are some issues that need to be resolved for their integration in the design process and use as an assessing design tool. Ideally, the designer could directly access the data of the BIM model, but data availability can be highlighted as one of the main difficulties involved in current rating systems. This can be solved by a link between the BIM model and the sustainability rating system.

4.1.3 Integration of external data

Infrastructure performance is a complex area that requires not just calculative analyses but the assessment of qualitative data and the acknowledgment of multiple perspectives. Sustainable infrastructure rating systems require significant amounts of non-project-specific information. This information is not typically carried within BIM design tools but by secondary analysis tools. Now few are able to interface easily and efficiently with existing BIM authoring tools. The BIM data only contains part of the necessary information to perform performance simulations. Alternatively, the focus could so potentially and greatly on alternative transportation that the impact of construction practices and materials could be missed. This may be solved by another element.

The third component of the prototype is the external data. The meaning of external data here is broad enough to cover climate data, traffic data and operation energy and material data and so on. In addition, human factors are gaining more significance. Different types and numbers of external data can be multiplied and expanded to the urban level in support of the infrastructure quality. Correlations can be analyzed between the external data and the design quality in the framework of sustainability rating systems.

4.2 Prototype design

4.2.1 Architecture

A comprehensive assessment of all aspects of sustainability requires an evaluation to determine whether sustainability has been sufficiently incorporated in the plans. Eddy & Nies (2008) gave seven steps in the order of operations to give sustainable solutions with the application of BIM as bellows:

- Understanding climate, culture and place
- Understanding the building type
- Reducing the resource consumption need
- Using free/local resources and natural systems
- Using efficient manmade systems
- Applying renewable energy generation systems
- Offsetting remaining negative impacts

Learning from the experience from the sustainable building design, two lessons are drawn. In order to deliver sustainable design, first way is to optimize the energy use and material consumption in the certain built environment, and the second way is to try alternative new method which is more cost effective than the original one. The former way depends on computational test using large quantities of data from the design, while the latter way need a quick what-if scenario visualization.

Given the large amount of environmental data that needs to be compiled for effective suitability analysis in the sustainable infrastructure rating system, BIM was used as an efficient tool for organizing, storing, analyzing, displaying and reporting the information. BIM allowed the creation and modification of the analysis that makes the best use of available data. BIM also supported methods to apply guidelines and criteria set by local and national management regulations.

The proposed BIM-based green performance calculation framework is based on three components:

1. A BIM software platform which supports 3D object-based BIM models with an underlying database of component information,

2. Green performance databases which contain all the items in the checklist in the sustainable infrastructure rating system and are accessible in the BIM software platform, and

3. External data excluding the categories contained in the BIM software platform but required in the green performance databases.

Five major steps of BIM analysis for environmental in the guidance of sustainability rating system include (but not limited to):

1, Definition of the proper rating system for the analysis

2, Definition of data needs

3, Acquisition and preparation of the data

4, Creating BIM models containing the data

5, Evaluating results and refinement of the model

Following the above principles, a framework integrating BIM and the sustainable infrastructure rating system is developed as showed in Figure 2.

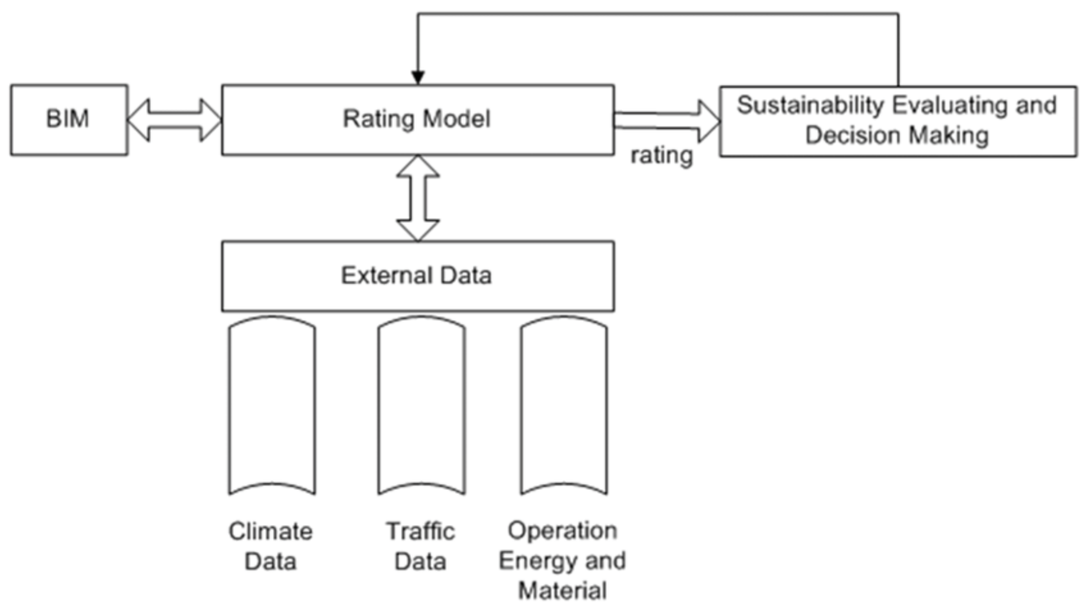

Figure 2 A framework integrating BIM and the sustainable infrastructure rating systems

These three components are highly interdependent to construct a systematic view on the design process. In the framework, the BIM model need the modification of its containing climate data, traffic data and operation energy and material data to be used as a source for rating. These external data holds one of the key positions in the integration. The decision-making activity will be based on the rating model under the assessment of the chosen sustainable infrastructure rating system. If there is still lacking of information for evaluation and decision making, the rating model will trace back from the original BIM model and the external database. If the decision maker is not satisfied with the results, the rating model will go back where the environment is saved, thereby permitting correction of a previously plan. After several loops, the best-performed model can be selected as a candidate for the further development. Ideally, the rating process will take a minimal amount of time.

4.2.2 Recursion and backtracking

The architecture of the prototype in reality form a learn cycle for critical thinking. Figure 3 illustrates the sustainable design cycle. The original design program is translated into BIM models and then act as the raw information on which decisions are based. Related rating systems and local environmental data including climate and traffic data etc. are processed to orient for further analysis and revise. The same loop and logic are repeated continuously until the optimal decision is obtained. Finally infrastructure design decision makers gain an advantage of full awareness of the situation and flexibly fitting the local sustainability rating systems.

Continuous addition of external data and evaluation can directly going back to the design phase data and decision-making moments with ease using this prototype. By up-scaling to the multi project site in an urban context, the prototype can integrate both rich local environmental data and custom-made sustainability rating systems to monitor and analyze the sustainability performance of the infrastructure project, and trace back to the design data of certain time, continuously improving decision-making in the infrastructure life cycle management. More development will follow in terms of dynamic user interaction in order to maximize its usability.

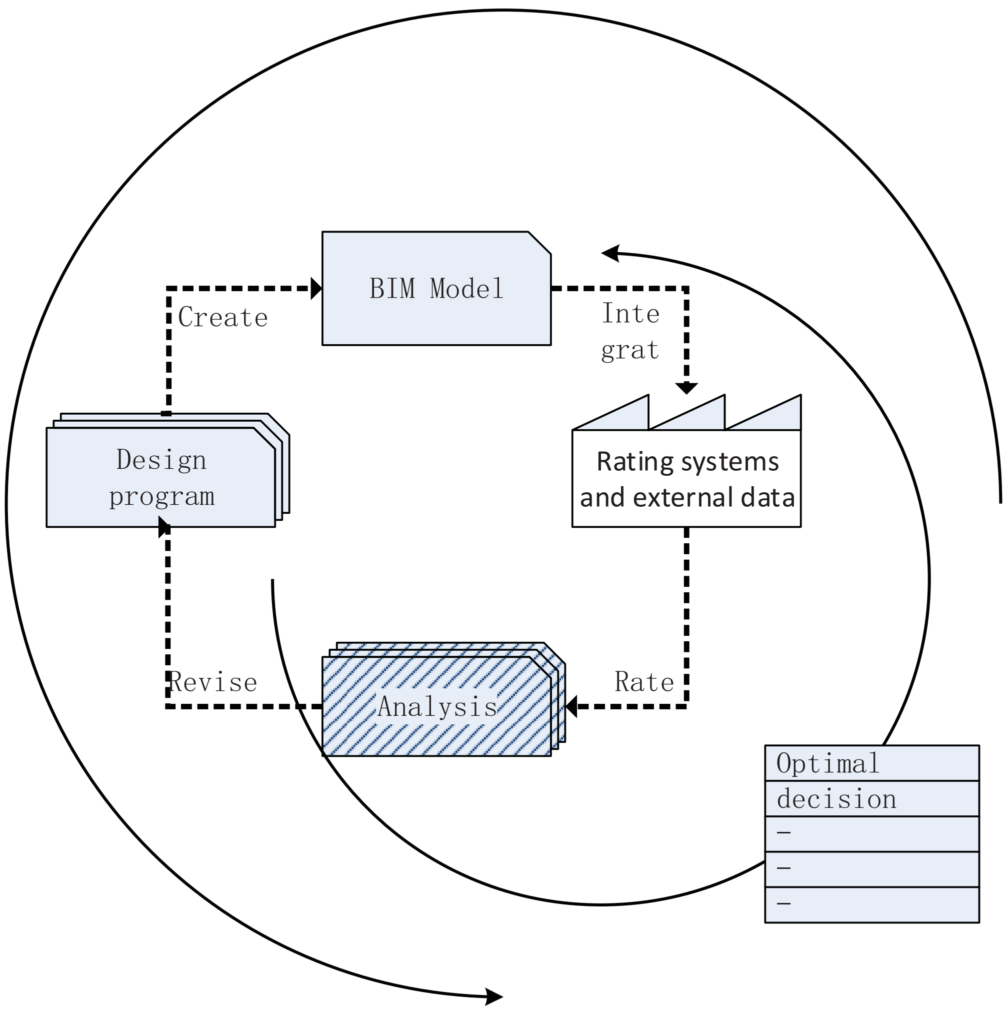

Figure 3 Sustainable design cycle

4.3 Implementation recommendations

According to the analysis before, one sustainability rating that can integrate it all is impossible. So locally used BIM software/platform for sustainability capability should be developed. Checking the transport infrastructure design models for compliance with sustainability code requirements and planning restrictions will be developed further.

The baseline of the transport infrastructure performance shall be generated by simulating the transport infrastructure with its actual orientation. BIM software companies can develop sustainable infrastructure rating system code-checking software plug-ins embedded in BIM software tools. The plug-in extracts local requirement data from online databases maintained by the government, as a service to local jurisdictions. Designers check their designs continuously as they evolve. Providing feedback directly to the model will make fixing problems easier than receiving an external report that needs interpretation before edits can be made.

5 Conclusion

This research proposed a prototype sustainable design management system based on the sustainability rating systems centered on BIM data. One of the key contributions of the system is to propose a process in which BIM is used as accelerators for innovation in the infrastructure project sustainability improvement. The system especially focused on the integration of various static and dynamic data in terms of design decision-makings considering environmental sustainability. Another contribution is the integration of the sustainable infrastructure rating system and the feedback loop to accelerate optimal decision. It provides an insightful view to the infrastructure design process compared with the BIM tools relying on the rating systems.

The future BIM model will be a system completely interactive with key infrastructure information, climate information, user requirements, and environment impacts, so that design integration and data return among all systems is immediate and symbiotic. Then once the infrastructure is completed, the BIM model will create an opportunity for asset management feedback loop. The proposed framework is conceptual in nature but provides the underlying foundation for developing a strategy for infrastructure designer to consider how BIM can lead to a sustainable advantage. Therefore, the framework is proposed as an ongoing conceptual approach for technology development and enhancement. With tools and wisdom intact, the combined future of BIM and sustainability can help us move faster and more elegantly to a sustainable world.

Acknowledgements

The first author is grateful to the Research program 'The Theory, Key Technology and Applied Research on Smart Building Management for Sustainable Development' (106112013CDJSK030003) funded by Key project of Natural Science Foundation of fundamental research funds for the central universities scientific research in China.

The paper was carried out in Delft University of Technology.

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