Model-based Systems Engineering and Building Information Modeling – Comparison and Synergies

Moritz von Ammon¹, Ingo Paech²

¹Invenio Systems Engineering GmbH, Harrlachweg 1, 68163 Mannheim, moritz.von-ammon@invenio.net
²Invenio Systems Engineering GmbH, Harrlachweg 1, 68163 Mannheim, ingo.paech@invenio.net

Abstract. This paper is part of a master’s thesis, trying to transfer functionalities from Building Information Modeling (BIM) into Model-based Systems Engineering (MBSE). It is not the final result of the thesis, but shows similarities, differences and possible synergies between the two approaches. This is being done to be able to transfer functionalities from BIM into MBSE in further research. MBSE is a model-based interdisciplinary approach that aims on the creation of successful, complex and interconnected systems. BIM is a model-based approach which regards the construction of buildings. It integrates three-dimensional models of different disciplines into one parametric three-dimensional model that not only contains geometric information, but also further properties. This paper wants to establish the idea of transferring project management-related functionalities from BIM into MBSE, respectively SysML models.

1 Introduction

This paper is based on a master’s thesis being developed in cooperation with Invenio Systems Engineering GmbH from Mannheim, Germany. It presents an interim result regarding the comparison of Model-based Systems Engineering (MBSE) and Building Information Modeling (BIM). The idea of the thesis is to transfer project management-related functionalities from BIM into MBSE. This idea rose at Invenio Systems Engineering GmbH when realizing that BIM includes several concepts that are also included in MBSE, but BIM additionally contains further functionalities regarding project management, which are not implemented in MBSE yet. At this stage, this paper wants to show that the combination of MBSE and BIM could be done and would add value to MBSE. It does not describe definite solution approaches on how this combination could be done in detail, although some ideas are being outlined at the end of the paper.

Systems Engineering is an interdisciplinary approach that aims on the creation of successful, complex and interconnected systems. It views the complete lifecycle of a system and optimizes coordination between different disciplines. It considers all requirements of the stakeholders and decomposes them into systems and sub-systems. Verification and Validation is also an important part of the Systems Engineering process [INC15, Hab12]. Model-based Systems Engineering supports those processes with
respective models [Wei14]. Next to the technical processes, traditional Systems Engineering also includes project management processes [INC15]. These non-technical processes are not yet implemented in the models of MBSE. Therefore, MBSE lacks a model which contains all relevant information (technical and non-technical) of a system. To solve this problem, BIM could provide valuable concepts and ideas. BIM is being used in the construction of buildings and provides a complete digital model of a building, before actual construction is being started. A BIM-model is a three-dimensional model containing architectural and geometrical information as well as information about used materials and energetic properties. Further, it contains project management-related information e.g. regarding costs and the construction process. The benefits of transferring those project management-related functionalities into MBSE would be the enabling of a model-based support of project management. Plans regarding costs, logistics or development processes could be improved by model-based analyses and simulations, leading to an increase in productivity.

2 The two approaches of MBSE and BIM

To begin with, the two approaches of Model based Systems Engineering (MBSE) and Building Information Modeling (BIM) are shortly outlined, to be able to compare them and identify synergies of the two approaches.

2.1 Model-based Systems Engineering

MBSE is a model-based interdisciplinary approach that supports the classic Systems Engineering development process with the formalized application of models [Wei14]. Using the Systems Modeling Language (SysML) it provides abstracted models, that describe the behavior, functional structure and requirements of a system. MBSE supports communication in interdisciplinary teams with different backgrounds by visualizing the system with its properties and functions. Additionally, SysML diagrams can be evaluated automatically (including simulation), supporting decision-making processes during the development [INC15].

2.2 Building Information Modeling (BIM)

BIM is a model-based approach used in the construction of buildings. It integrates three-dimensional models of different disciplines into one parametric 3D-model that does not only contain geometric information, but also further properties. The integrated BIM model contains information about costs and time planning. The different project participants (with diverse backgrounds) create their respective model (e.g. architectural model, structure model), which are then integrated into one “coordination model”. This coordination model is the basis for the interdisciplinary communication. Additionally, the models are evaluable, meaning that various model-based simulations can be done. This includes technical regards such as the required heating load of a building as well as project relevant simulations such as the simulation of the construction process [Hau16].
The different project participants that are affected by the BIM coordination model are depicted in Figure 1 (picture taken from [Hau16, p.116]). To be able to exchange data between different discipline-specific software-tools, BIM compatible software must be used by every project participant. Also, a neutral exchange format for data is necessary. For BIM, the format IFC (Industry foundation classes) is being used.

Figure 1. Users and stakeholders of a BIM model [Hau16, p.116]

Figure 1 does not imply that every project participant is working simultaneously in the same model. Instead, every discipline creates its own models that are integrated into the coordination model (“Mutual Building model”). In addition to the classic roles of building projects depicted in figure 1, the definition of BIM-specific responsibilities is recommended to ensure the quality of BIM-specific processes like integrating the different models into the coordination model [Pil16]. The following BIM-specific roles and responsibilities are defined by [Pil16]:

- Architect
- Facility Manager
- Structural Engineer
- Building owner
- Technical Building Equipment planner
- Building authorities
- Construction Manager
- Specialists

The different projec...
- **Strategic BIM-Manager** for defining BIM-goals and a plan of procedure for activities related to BIM (close cooperation with BIM-Manager)
- **BIM-Manager** (or BIM-Planner) for coordination of the BIM related activities
- **BIM overall coordinator** (in major projects) for coordinating the individual specialists of the different disciplines
- **BIM coordinators** for coordination of BIM-processes in their respective disciplines
- **BIM constructors** for creating the individual BIM-models in their respective discipline

Figure 2 is taken from [Hau16, p. 132] and depicts the process of creating and versioning the coordination model and the involved BIM roles.

![Diagram of BIM coordination processes](image-url)
The benefits of using BIM in building constructions include an improved reliability of planning documentation, an improved transparency, communication and coordination due to the model-based approach, and reducing of costs during development as well as during operation and the complete life cycle of a building (the BIM models can be used to support maintenance of the building) [Hau16].

3 Comparison

In this chapter, the two approaches are being compared to identify concepts, that could be usefully transferred into MBSE. Similarities are:

- Both are holistic, interdisciplinary approaches
- Simulation and Assessment of models is available
- Interdisciplinary coordination is enabled through consistent models
- Optimized communication and data exchange between all project participants
- Both approaches allow the depiction and linkage of requirements to specific parts of the model; assessment of the fulfillment of requirements is available
- Both approaches use models to ensure high quality of documentation and planning

The main difference between MBSE and BIM is that the SysML diagrams of MBSE model the behavior and (abstract) functional structure of a system, while a BIM-model is a concrete three-dimensional model containing further (project management-related) information of the included elements.

BIM-models contain information regarding costs, time planning, support of construction and support of operation, which are not yet available in SysML. However, some functionalities, such as the generation of quantity lists could be done using SysML models (e.g. evaluating the amount of a specific component), but missing information about costs inhibit the precise calculation of material-related costs.

In summary it can be said, that the BIM approach includes project management-related information, which are not yet implemented in the functional models of MBSE, although the possibility of implementing those functionalities in MBSE is visible.

This is only a partial comparison of selected features that have an added value to this paper. Further comparisons could be done in future research.
4 Synergies

Next, possible synergies of MBSE and BIM are outlined. The described similarities are not being viewed, since these functionalities are already implemented in both approaches. Functionalities that could be transferred from BIM into MBSE are implied by the differences between the two approaches. The main differences that have been identified are:

- BIM uses parametric three-dimensional models, SysML uses abstract models (both models contain further information about properties and functionality)
- Both approaches allow the linkage of requirements to the system model, but the linkage of requirements to respective parts of geometric 3D-models is not feasible in SysML, which only provides abstract models
- BIM models contain information regarding costs of a project, SysML diagrams do not
- BIM models contain information regarding time planning of a project, SysML diagrams do not
- BIM models contain information that support the construction process (building sequence simulation), respective SysML diagrams supporting manufacturing do not exist
- The BIM approach enables the model-based support of Facility Management and Maintenance, respective SysML functionalities for maintenance activities do not exist
- BIM uses a central model (“coordination model”) that contains all models from the different disciplines, improving the communication of all project participants through a consistent model of the building. The Lack of an overall inter-compatibility of software tools (Integrated tool chain) prevent this in MBSE

The use of three-dimensional models in combination with SysML is not current practice, since SysML is an abstract modeling language, describing functional structure. An approach for the connection of three-dimensional CAD models with SysML has been described in [Pol13]. A neutral exchange data format would be required, when pursuing such a project (like the IFC format used in BIM). The implementation of requirements into 3D-models would be possible if the connection of SysML models and three dimensional models would be realized, e.g. as depicted in [Pol13]. This would require a functioning tool-chain and could enable the developers of a system to view the relevant requirements of a specific component directly out of CAD models, as it is already possible in BIM models. This would require the linkage of SysML-blocks to individual components of the system in a CAD-model. This could include project management related requirements (e.g. costs for specific components).
The implementation of information regarding costs into SysML could be a valuable addition for the project management. This is not limited to cost-information linked to individual elements of a model, but also includes automatic evaluations and analyses. Using such evaluations, not only production costs could be estimated and reduced early in the development process, but also operational costs due to cost-related simulations of the running system.

This could, for example, be done by defining a “cost model” containing new blocks or attributes regarding costs (by using stereotypes). For a more complete procedure regarding cost calculation additional stereotypes of actors could be defined (e.g. “project manager” or “controller”) to describe use cases and specific activities in SysML that support the financial planning of a project. Such diagrams could then be used to perform automatic cost evaluations via parametric diagrams. This implementation of information regarding costs into SysML models could lead to an overall reduction of costs of a system. For example, a design-to-cost development process could be supported through direct connection of a cost model with a system model or with requirements that regard financial aspects of a system.

Regarding the model-based support of time planning, the modeling and development process could be supported by implementing new functionalities regarding time planning into SysML. For this, the possibility to model the dependency of different sub-systems could be implemented into SysML, meaning that the developers would be enabled to detect which sub-systems have to be completed in order to start developing another sub-system out of the SysML model. This is similar to the “building sequence simulation” used in BIM and could reduce exceeding of time limits in a project through improved clearness and organization of the modeling process.

The implementation of a model-based support of the manufacturing process could be done by using activity diagrams and linking them to the respective elements of the system model. This would help manufacturers to develop and prepare a manufacturing process early in the development process of a system. Also, it could support the coordination of suppliers (just in time- and just in sequence-delivery) and general logistics. However, a complete “building sequence simulation” (as it is used in BIM) is not realizable with activity diagrams, as they only provide a workflow and possible decision-making points, but do not identify possible conflicts and problems. To implement this functionality, further research is necessary.

The model-based support of Facility Management could be translated into “model-based support of the operation of a system” when talking about general technical systems. This could be implemented by trying to create an operational manual directly out of the SysML models. For example, behavior diagrams (like activity diagrams or use case diagrams), that describe interaction of a user with the system, could be used to automatically create a text-based manual.

The implementation of an interdisciplinary model that is being used by every project participant (like the coordination model in BIM) would require the different software tools (CAD-tools, SysML modeling tools, …) to be fully compatible with each other. This would require a neutral interchange format. Regarding the modeling process in SysML, the different disciplines (mechanics, electronics, software) would have to work on a central SysML model instead of creating their own respective models. This would be a mostly methodological change, requiring the definition of respective processes and
standards. This could lead to an overall improvement of communication between all project participants and thus to an increase of quality.

The benefits of implementing the described functionalities into SysML could be an overall reduction of cost and duration of a system developing process. This could be realized by implementing the factors cost and time directly into the SysML model. A manufacturing process could be developed and planned during the development of a system, reducing time-to-market. The effort (and costs) for creating user manuals and other documents supporting the operation and maintenance of a system (e.g. a Maintenance plan) could also be reduced by creating these documents automatically out of SysML diagrams (e.g. activity diagrams).

Figure 3 illustrates some functionalities of BIM that could be implemented into the SysML including the respective benefits. The functionalities shown in figure 3 are those which are considered most suitable and valuable for the MBSE process. These are the following three functionalities: model-based support of cost planning, model-based support of time planning and methodological transfers. This is being justified with the “magic triangle” of project management [e.g. Mad2017]: time-cost-quality. Since the aspect of quality is already covered with the classical Systems Engineering approach, the two aspects cost and time are viewed as most relevant for the transfer of functionalities from BIM into MBSE. These two aspects are partly implemented in the classical Systems Engineering approach but not yet in the models of MBSE. The methodological transfers (this regards mainly the usage of a central model for all project participants) additionally covers the quality aspect of the triangle, by adding possible improvements to the modeling and development process of MBSE. Figure 3 visualizes these three implementations from BIM into SysML and the respective benefits.

Figure 3. Functionalities of BIM that could be usefully implemented into SysML
The presented possible synergies and benefits are exemplary to illustrate and promote the idea of transferring project management-related functionalities from Building Information Modeling into Model-based Systems Engineering. The actual realization and detailed analysis of benefits of this idea is going to be done in later stages of this project and will possibly be presented in an additional paper.

5 Conclusion

5.1 Reference to similar projects

In 2017 a working group of INCOSE UK has done a comparison between MBSE and BIM. Their paper found several similarities between the two approaches [Tow17], justifying this paper. Another paper from 2013 described the combination of BIM models with SysML models. This aimed to an integrated tool chain between SysML-Tools and CAD tools [Pol13]. The comparison between MBSE and BIM has been (partially) done [Tow17], as well as the transfer of technical functionalities. What has not been done yet, is the implementation of functionalities regarding project management.

This paper has presented the idea of using BIM-related concepts to implement such functionalities into MBSE. It aims to eventually implement functionalities into MBSE by implementing them into the SysML. This is going to be done in further researches.

5.2 Summary

This paper presented the idea of combining BIM and MBSE. In summary, it can be said that there are several similarities and synergies between the two approaches of Model-based Systems Engineering (MBSE) and Building Information Modeling (BIM). A comparison between the two approaches has been outlined and possible functionalities that could be transferred from BIM into MBSE have been identified. Those functionalities are regarding project management as well as later stages of the product life cycle such as operation and maintenance.

Benefits of an implementation of those functionalities have been described and include reduction of costs throughout the affected stages of the life cycle. The benefits of three functionalities (cost planning, time planning and methodology) that would presumably add the most value to MBSE have been further outlined.

It has been shown that the idea of BIM including concepts, that could be usefully implemented into MBSE, is reasonable. Some basic ideas for the realization of such an implementation have been given. The master’s thesis, on which this paper is based, will conduct further research on how to realize the implementation of the described BIM functionalities into MBSE.
References


