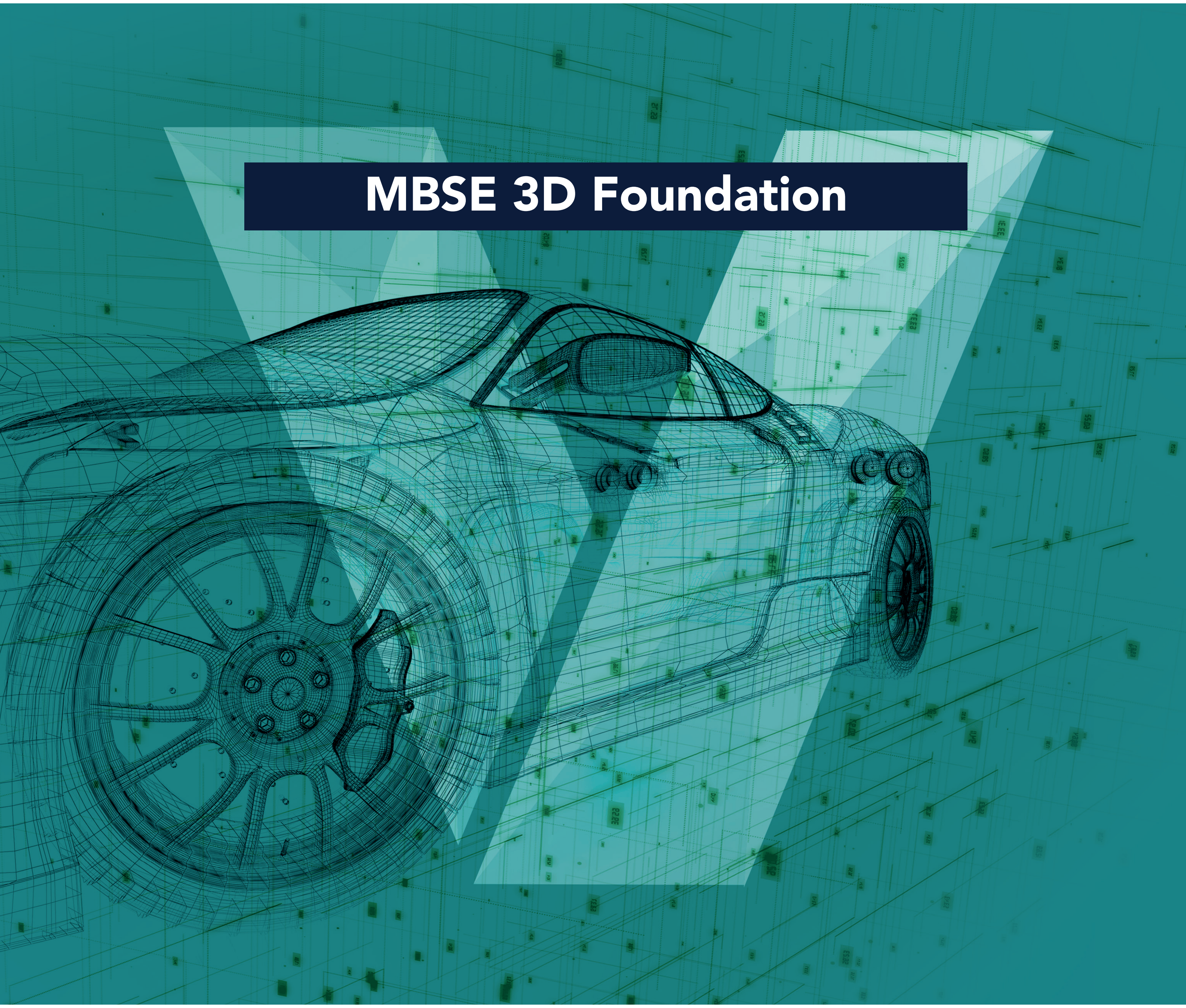
prostep ivip

Recommendation



prostep ivip Recommendation

MBSE 3D Foundation

3D Visualization in MBSE

Abstract

Products and Systems are getting more complex over the last years due to a trend to interconnected products, which are often realized as Systems of Systems (SoS), and further influences like the rising globalization and more stringent regulations. New development approaches emerged to handle this complexity and to allow the realization of such complex systems. One of these approaches is Systems Engineering (SE), where a system is developed from the beginning in a holistic approach to consider all influences and interfaces. The Model-Based Systems Engineering (MBSE) uses models to describe the system in its requirements, architecture, behavior and many more aspects. This allows a single-source-of-truth-approach, dynamic usage of the constantly updated information stored in the system model as well as a better understanding, communication and collaboration inside of the project.

Jupiter Tessellation (JT) is the international standard for 3D visualization. It is an open standard format and thus independent from the used Computer Aided Design (CAD) system in use. Together with STEP AP242 XML it is used to share information about components in respect to geometry (JT file) as well as technological aspects (AP242 XML). It allows an easier communication between project members over domains.

As MBSE and JT both support the collaboration and communication, it is obvious to look at both to find synergies and general benefits. The current recommendation shall deliver the following:
- An overview of the capabilities and elements of JT and MBSE
- Current use cases of JT in MBSE
- Possible use cases for further combination of JT and MBSE
- Recommendations for the further research and development of JT in MBSE

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Table of Content

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Abbreviations, Definitions, References

Abbreviation	Meaning
3DMDM	3D Measurement Data Management Workflow Forum
AR	Augmented Reality
API	Application Programming Interface
B-Rep	Boundary Representation
CAD	Computer Aided Design
CAPP	Computer Aided Production Planning
CAQ	Computer Aided Quality assurance
CDLC	Cross-Discipline Lifecycle Collaboration
DDP	Digital Data Package
DMU	Digital Mock-Up
FMEA	Failure Mode and Effects Analysis
FMI	Functional Mock-Up Interface
FMU	Functional Mock-Up
FTA	Failure Tree Analysis
JT	Jupiter Tessellation
JT IF	JT Implementor Forum
JT WF	JT Workflow Forum
KernML	Kernel Modeling Language
KPI	Key Performance Indicator
LOD	Level of Detail
MBSE	Model-Based Systems Engineering
MOF	Meta-Object Facility
OMG	Object Management Group
OSLC	Open Standards for Lifecycle Collaboration
PMI	Product Manufacturing Information
RFP	Request for Proposal
SE	Systems Engineering
SoS	Systems of Systems
STEP	Standard for the Exchange of Product Model Data (ISO 10303 series)
SysML	System Modeling Language
UML	Unified Modeling Language
VDA	German Association of the Automotive Industry
VR	Virtual Reality
XMI	XML Metadata Interchange
XML	Extended Markup Language

1 Management Summary

The JT Workflow Forum (JT WF) is a collaboration of prostep ivip e.V. and the German Association of the Automotive Industry (VDA), which aims to establish Jupiter Tessellation (JT) as process format in industry. Major goal of the project is the specification of current and future demands and requirements on JT. Together with the JT Implementor Forum (JT IF) further goals are the validation of the specified demands and requirements in the cooperating companies as well as the documentation and prioritization of processes in form of use cases.

"Current products are getting more interconnected, intelligent and thus more complex. As means against this complexity current development processes are refined." (translated from Auricht 2018, p. 25). One of these approaches for refined processes is Systems Engineering (SE), which focuses on the system as a whole and thus supports the realization of complex products and projects. An even further integrated process is the Model-Based Systems Engineering (MBSE) where models are used instead of documents for the description of the system.

JT as a visualization format for three-dimensional (3D) models can support this method and can be used for information storage and communication activities. With its visualization aspect, it supports the communication between different stakeholders and helps them to better understand the modeled information.

Since 2012 JT is the standard format for the visualization of 3D-Data (ISO 14306:2012). Typical use cases are Digital Mock-Up Units (DMU), Design-in-Context and communication, e.g. with customers or the production (prostep ivip e.V. 2009, p. 12–18).

Goal of this recommendation is the exposition of the current and future role of 3D visualization in MBSE, with special focus to JT as standard format. Therefore, JT will be described in more detail (section 2.1) followed by MBSE in general (section 2.2) and current standards, working groups as well as benefits and challages of MBSE. Section 3 will present some current (section 3.1) as well as future (section 3.2) use cases of JT in MBSE. Eventually the paper will be summarized and recommendations will be presented.

2 General aspects of JT and MBSE

2.1 JT and STEP AP242 XML in general

Since 2012 JT is the standard for visualization of 3D data (ISO 14306:2012). It is used for various scenarios, e.g. Design Reviews, and is supported by a multitude of software tools. Some general aspects mentioned in the current version of the standard of 2017 are (ISO 14306:2017, xvii):

- "built-in support for assemblies, sub-assemblies and part constructs;
- a flexible partitioning scheme, supporting single or multiple files;
- [B]-[R]ep solid shape representations to provide precision to the light-weight viewing processes;
- product manufacturing information [(PMI)] in support of paperless manufacturing initiatives;
- precise and [coarse] wireframe shape representations;
- discrete purpose-built levels of detail [(LOD)];
- triangle sets, polygon sets, point sets, line sets and implicit primitive sets (such as cylinder, cone and sphere);
- a full array of visual attributes such as for materials, textures, lights;
- hierarchical bounding box and bounding spheres;
- data compression that allows producers of JT files to fine tune the trade-off between compression ratio and fidelity of the data […]
- offline optimizations of the data contents, i.e. file granularity and flexibility optimized to meet the needs of enterprise data translation solutions;
- asynchronous streaming of content, i.e. viewing optimizations such as view frustum and occlusion culling and fixed-framerate display modes;
- layers, and layer filters."

Since it is the standard for the visualization of 3D data, it is supported by a multitude of software systems working with 3D geometries. Some examples are the Computer Aided Design (CAD) for mechanical design, Computer Aided Process Planning (CAPP) and Computer Aided Quality Assurance (CAQ) with IPS Path planner (Fraunhofer-Chalmers Centre 2019) and GOM Inspect (GOM GmbH) as application examples.

The JT WF investigates STEP AP242 XML as closely related to JT. As ISO 1030-242, it is part of the ISO Standard for the Exchange of Product Model Data (STEP) series 10303 and currently under review as ISO/DIS 10303-242.2. The recent official version is ISO 10303-242:2014. It is meant to store information regarding the component of interest that cannot or shall not be stored inside of the JT part, such as non-geometrical technological information.

Katzenbach et al. have discussed the potentials of combining both standards. Their main use cases have been Design-in-Context and the supplier integration, where the supplier delivers complete modules and thus the pure geometrical information is not sufficient. Potential benefits of the combination of both standards have been pointed out and the development of both standards has been driven forward.

2.2 Model-Based Systems Engineering (MBSE)

With a rising complexity of modern products and a trend from single products to Systems of Systems (SoS) where the produced system consists of multiple subsystems and the integration of multiple domains is a mandatory step, new approaches for development are demanded. One of these approaches is Systems Engineering (SE).

> *"Systems Engineering is a transdisciplinary and integrative approach to enable the successful realization, use, and retirement of engineered systems, using systems principles and concepts, and scientific, technological, and management methods." (INCOSE)*

The classical SE is document-based and therefore hard to keep updated and understandable for every domain. The interdependencies of the documents are hard to track and the revision has to be done manually for every change of a document. To tackle this challenge the Model-Based Systems Engineering (MBSE) has been introduced.

> *"Model-based systems engineering (MBSE) is the formalized application of modeling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases." (INCOSE Technical Operations 2007)*

This allows the usage of views on the modeled data, such that every domain can see, understand and save information relevant to them. Additionally, the system model can be seen as single-source-of-truth, which is constantly updated and thus eliminates manual effort to maintain different documents. With the usage of trace links, which are modeled dependencies between models or elements of models, the influence of changes can be seen and tracked down to every artefact in the development process.

The process for MBSE is most of the time modeled as a V-Model as can be seen in the following figure taken from Buchholz et al.

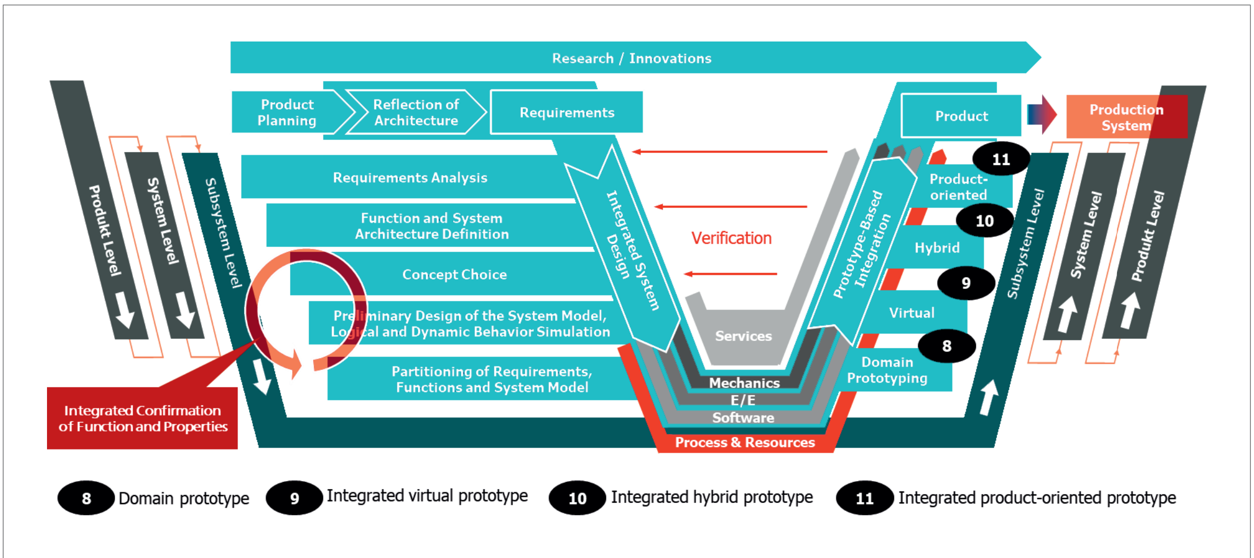

Figure 1: Extended V-Model for MBSE (Buchholz et al. 2018, p. 7)

Beier et al. have analyzed the left side of this process and stated the models that are created and used in these phases (Beier et al. 2017, pp. 26–30):

1. **Product Definition**: no models, results are high-level requirements for the overall product defined by customer demands, mature technologies and management expectations
2. **Product requirement analysis**: requirements model, as reviewed, validated, detailed, structured and refined form of the high-level requirements
3. **Functional architecture definition**: functional architecture, showing functional parameters and relations between functions based on the requirements
4. **System structure**: System structure, structure of elements that can achieve desired functionalities of functional architecture with attributes
5. **System Architecture Definition**: System architecture, combination of system structure and functional architecture, with trace links between elements of system structure and functions
6. **Concept selection**: no new model, investigate how the elements of the system structure can fulfill functions an consider alternative concepts
7. **Behavior modeling/simulation**: behavior model, combination of previous diagrams and parameters to validate correct functionality and adapt parameters

The product definition as first phase in this process is only performed for the overall system or product definition, but the rest is performed for every level the system is structured to. The level of detail should only be as deep as the application requires and generic enough to stay valid for all underlying levels. The behavior modeling and simulation on the different systems levels allow an early revision of the developed product and prevent expensive design changes in the late phase of the development process.

When defined and used in the early stage of the product development cycle, the models can be used in the integration and verification phase on the right side of the V-model for the validation and verification with multiple phases of (partly) digital prototypes. Each domain can test their designed artifacts in domain prototypes and as seen in Figure 1 the system can be verified as whole before the production and usage of a physical prototype.

Husung et al. have presented an overview of possible use cases in MBSE which is shown in the following figure.

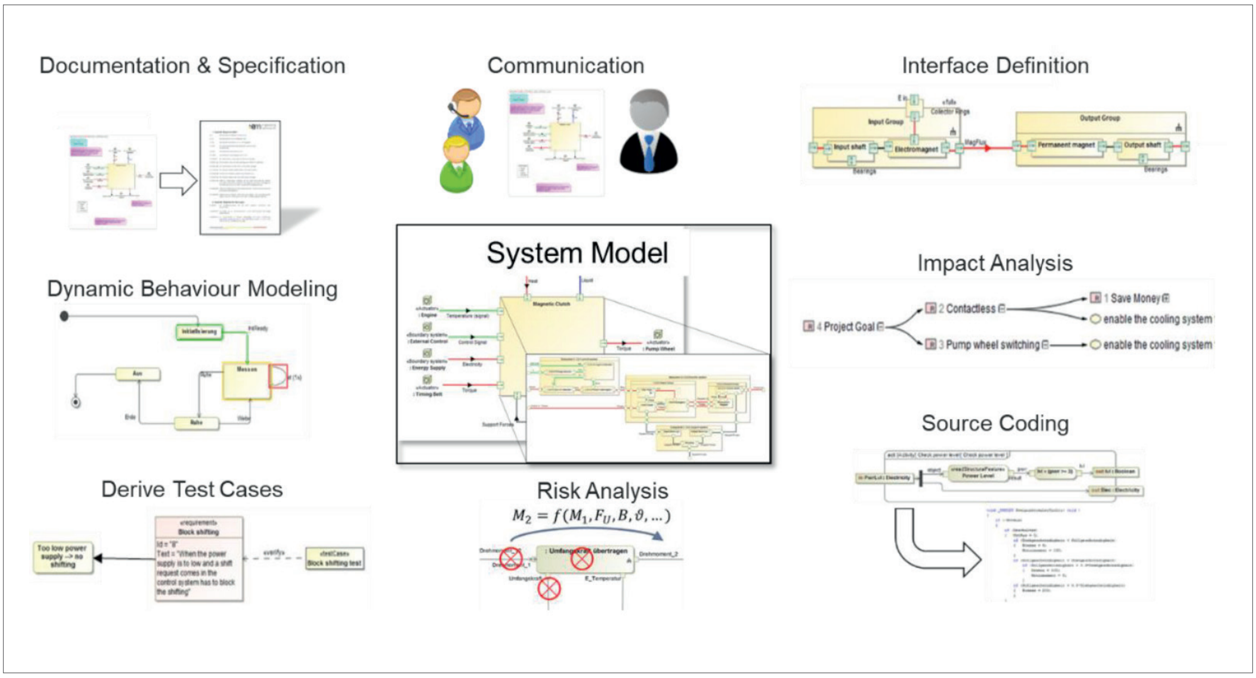

Figure 2: Use cases for MBSE (Husung et al. 2018)

The use cases shown in Figure 2, including Documentation & Specification, Communication, Interface Definition, Dynamic Behavior Modeling, Impact Analysis, Derivation of Test Cases, Risk Analysis and Source Coding rely on a an overall system model seen in the middle of this figure. This system model "[…] includes system specification, design, analysis, and verification information. [It] consists of model elements that represent requirements, design, test cases, design rationale, and their interrelationships." (Friedenthal et al. 2011, p. 17).

For most of these model elements, the System Modeling Language (SysML) is sufficient for the definition. It can be used for the requirements model, the system structure, the functional architecture, the system architecture and (partly) the behavior modeling. SysML has been and still is actively developed by the Object Management Group (OMG). The specification is available since November 2019 as version 1.6 (Object Management Group 2019). Version 1.7 and 2 are currently under development in parallel. The current version 1.6 offers the following types of diagrams for the representation of model elements:

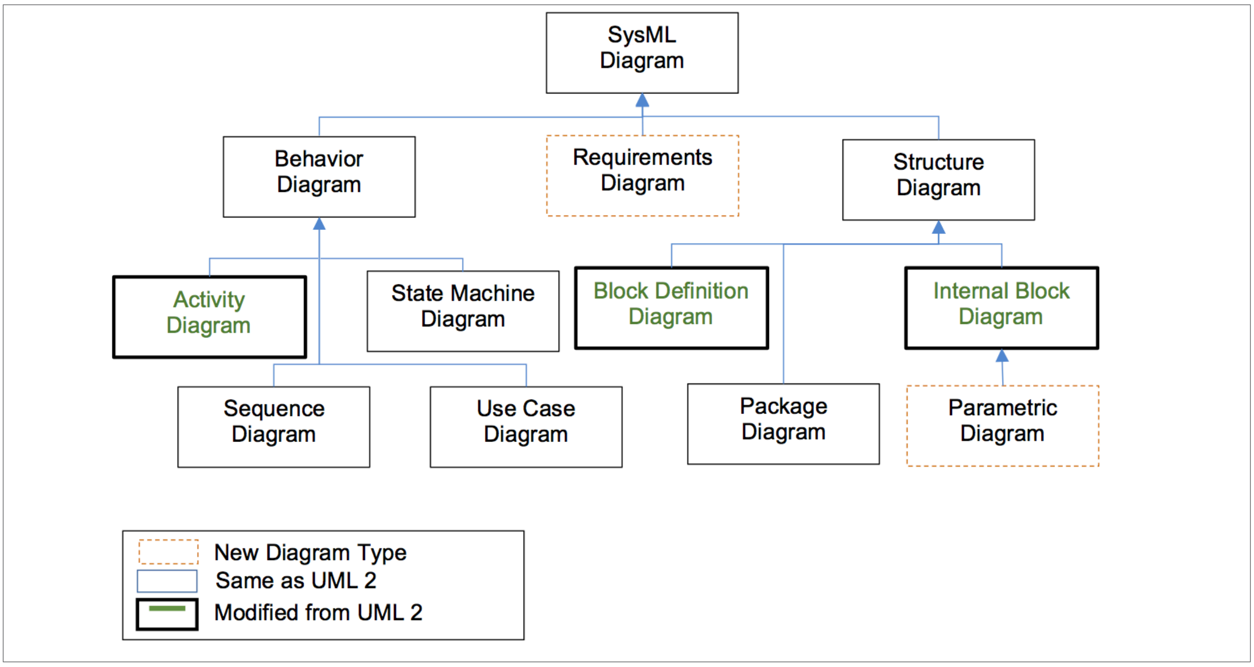

Figure 3: SysML Diagram types (Object Management Group 2019, p. 211)

Beside these diagram types, there is a variety of so-called stereotypes, attributes and profiles, which can be used to extend the functionality of SysML. An example is the Safety and Reliability Analysis, which defines new stereotypes and profiles to include Safety aspects into UML (Unified Modeling Language), which is currently the base for SysML. With these profiles UML is extended with the functionality to define safety and functionality aspects like Fault Tree Analysis (FTA) and Failure Mode and Effects Analysis (FMEA) (Biggs et al. 2018). Many companies define their own profiles and stereotypes to adapt SysML to their needs.

The second version of SysML, known as SysML v2, is meant to be the next step of SysML to support graphical modeling in MBSE. Weilkiens described it as the "next generation modeling language for the next 15-20 years".

With the final version of SysML v1.0 in 2007, a Request for Information (RFI) has been started in 2009 followed by a Request for Proposal (RFP) Development from 2014 until December 2017. Since then, a Workgroup is collecting feedback to the RFP for the further development of SysML v2. The submission, which has been shifted from 04th of November 2019 to Q2 2020, is set as starting point for the development of this SysML version. A final version might be seen in Q2 2022. Figure 4 shows the current Roadmap of SysML v1 and v2.

Weilkiens has presented some features of the upcoming SysML v2 including the following (Weilkiens 2019, pp. 11–24):

- New language architecture: the new version will no longer be based solely on UML and thus be not restricted by the software-development-based UML. A new language architecture called Kernel Modeling Language (KernML) is in development and shall be used as basis for SysML v2. To allow an easier adoption, SysML v2 profiles for the current UML based standard are developed in parallel. This language architecture is the base for the further features.

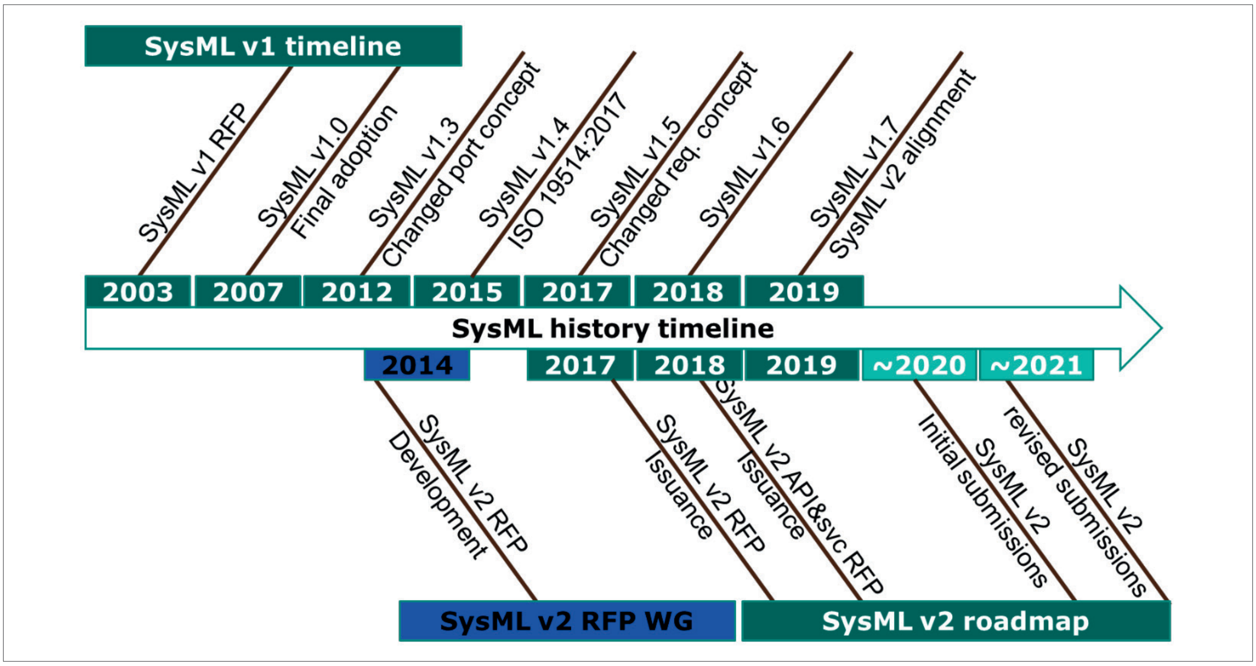

Figure 4: SysML v2 Roadmap taken from (Jastram 2019)

- Materials: As an important step towards interaction with 3D representations, SysML v2 shall implement named material and property representation in model libraries and assignment to different physical components.
- API: To allow tool-independence and easier implementation, a standardized and tool-independent Application Programming Interface shall be included, that allows reading and writing access to the system model without the need for a specific SysML-tool
- Basic geometries: basic 2D and 3D geometries, including their base coordinate frame, shall be representable by the SysML v2. This allows an even better visualization and understanding.
- New diagrams: Beside the classic diagrams, tables and matrices as well as text, dynamic visualization and the already mentioned geometry visualizations shall be included in SysML v2. (see Figure 5)

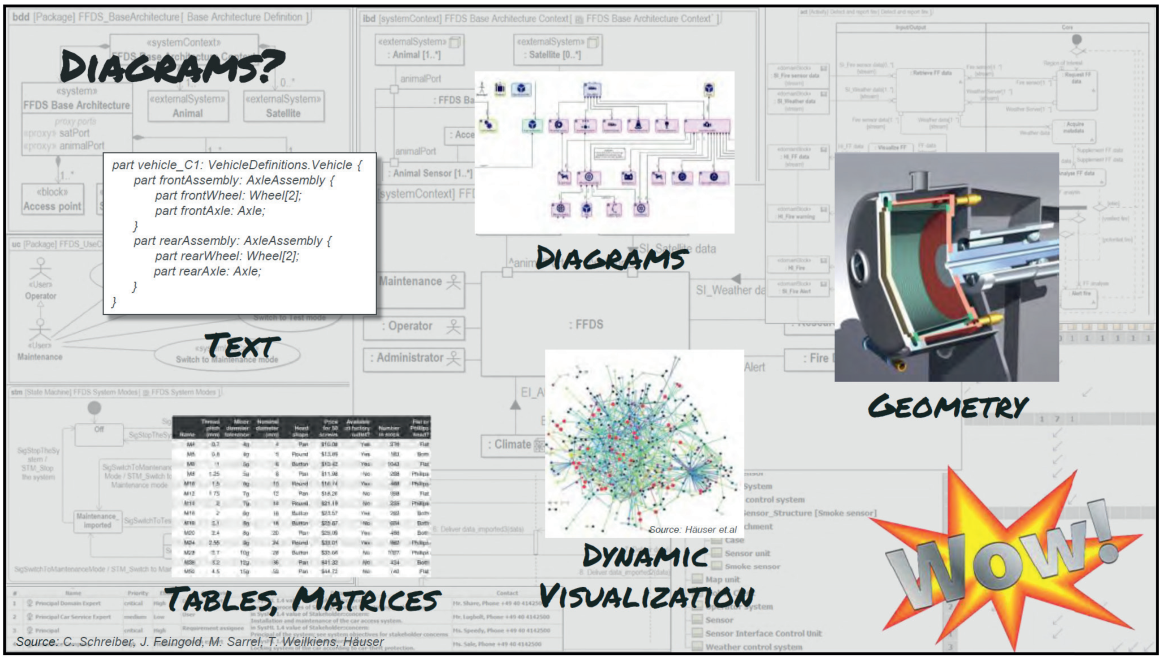

Figure 5: SysML v2 interaction/visualization formats shown in (Weilkiens 2019)

- Model-Based Requirements Engineering: While in current SysML versions the modeling of the requirements is mainly the combination of blocks that are filled with text, the v2 shall bring a fully model-based approach, where textual requirements are only supported but not mandatory.
- Support of analysis and decisions: Decisions and Analysis shall be supported more in the SysML v2
- Usage-oriented modeling: In the current version of SysML it is necessary to define block definition diagrams (bdd) as a framework before the actual interrelationship can be modeled in internal block diagrams (ibd). SysML v2 offers the possibility to model the ibds directly.
- Support of digital twins: It shall be possible to model digital twins. Currently there has been no further information, how this shall be achieved.
- Interfaces between domains: The interfaces between the domains E/E, Mechanics, Informatics, Logical Design and Requirement Design shall be easier to connect.
- Version and Timestamp: As versioning and timestamping is important in today's development procedures, SysML v2 shall offer a possibility to apply timestamp and version data directly onto the model elements and not only to the full model or diagrams.
- Data protection: data protection control for model elements shall be implemented in SysML v2 as well.
- Cause-Effect-relationship and Risk: As has been shown by the example of Biggs et al. on top, the Safety and reliability aspects are currently not consistently included and shall be included directly in SysML v2.
- Navigation: SysML v2 shall include a hyperlinking functionality to link model elements internal or externally.
- Variant Modeling: The ISO 26550 for product line engineering and management shall be fulfilled by variant management integrated in SysML v2. This includes variation points, variants, variability expressions and variant binding.
- New types: beside the primitive types from SysML v1, software development types like integers, reals, strings, Booleans, times/dates and complex there shall be an implementation of collection types like sequence, set, ordered set, bag, vectors, matrices and higher order tensors. Thus, it is possible to describe most of the imaginable mathematical & physical problems as well.
- Harmonization of sequence and activity diagram: The previous activity and sequence diagram have been doing the same but in different forms, without supporting each other. With the upcoming version, they shall be usable as different diagram representations of the same model elements.
- Behavior and structure: The integration between behavior and structure shall be enhanced considering mainly their inputs and outputs.
- Test Cases for conformance: To support the implementation of SysML v2 test cases for conformance checks shall be included in the meta model and profiles as well.

Focusing on the beginning of the list, it can be seen, that 3D data is seen as important aspect for the correct usage of MBSE and shall be further implemented into the upcoming standard.

That said one has to consider that MBSE is not only SysML. SysML is a standardized and widely spread graphical modeling language that allows an easier and understandable definition of System Models and the mentioned use cases of Figure 2. The prostep ivip SysML Workflow Forum (SysML WF) investigates how models described with SysML can be used for collaboration in the automotive domain. Beside SysML there are multiple other languages and methods such as OPM or Arcadia that can be used for the system definition.

2.3 Additional standards for collaborative Systems Engineering

Further standardized formats for the usage in MBSE have already been presented in the PSI for collaborative Systems Engineering based on IT Standards (prostep ivip Association 2019, p. 7) and can be seen in the following Figure 6. In the early stage of development, the standards ReqIF (exchange of requirement models), XMI (XML Metadata Interchange) and FMI (Functional Mock-Up Interface for the coupling of simulation models) have attention in this domain, while JT as visualization format is mainly used in the late development phase. OSLC (Open Services for Lifecycle Collaboration) on the bottom of the diagram is getting more attention as overall framework (PTC 2019). The SysML WF currently discusses XMI as possible useful standard for the model exchange. Some vendors like for example NoMagic use it as their native format for their system modeling tools.

Reference/Short name	Description/Content
Functional Mock-Up Interface (FMI)	Interface to combine multiple models, mainly used for co-simulations
ISO 10303-233 – Systems Engineering	Application protocol for the representation of system engineering data, independent from the domain
ISO 10303-242 – Application Prototcol: Managed model-based 3D engineering	AP242 XML, as mentioned in the beginning used to store relevant information, that shall not be directly applied to the JT file
Requirements Interchange Format (ReqIF)	Interchange Format for Requirements
SysML v1.6	Current SysML standard
SysML v2	Upcoming SysML standard
XML Metadata interchange (XMI)	XML based format to exchange metadata, expressed in Meta-Object Facility (MOF)

Table 1 – Standards related to JT and MBSE

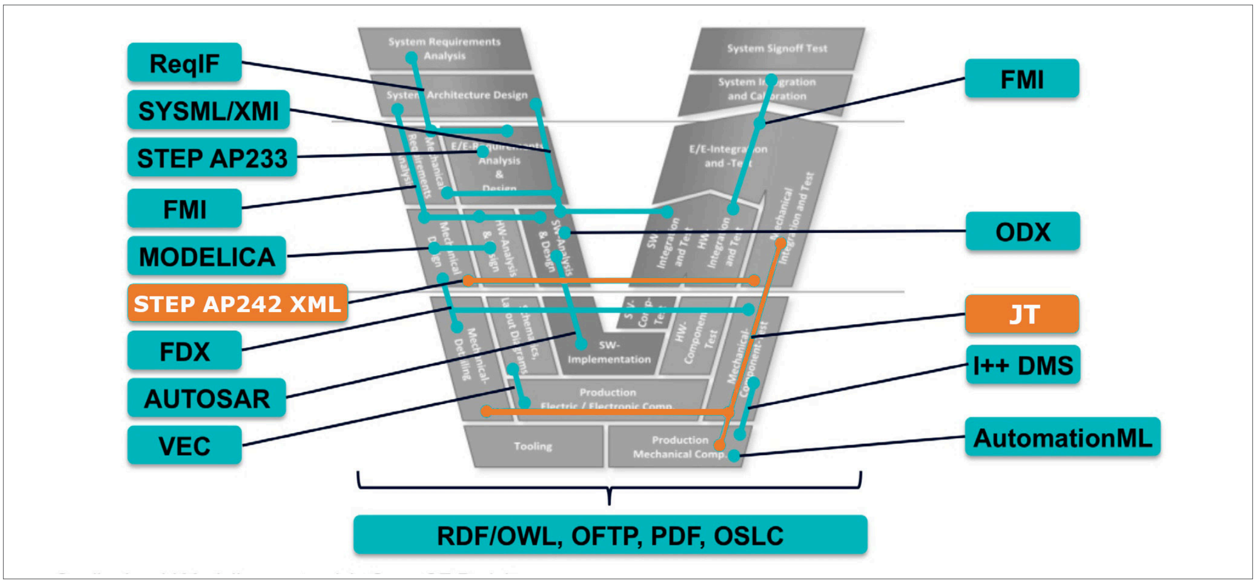

Figure 6: JT in V-Model by (prostep ivip Association 2019, p. 7)

2.4 Working Groups for MBSE

As MBSE is an important and broadly investigated topic, multiple working groups are focusing on MBSE related topics. In the following short overview, some of the most relevant working groups for the combination of JT and MBSE shall be mentioned (see Table 2).

As top-level organizations the prostep ivip, the OMG and the International Council on Systems Engineering (INCOSE) with its German chapter "Gesellschaft für Systems Engineering" (GfSE) have been chosen. They shall be considered as partners for further investigations in the current topic.

prostep ivip	OMG	INCOSE	GfSE
• JT WF • SysML WF • Smart SE • OSLC • 3D Measurement Data Management Workflow Forum (3DMDM) • CDLC Forum • Digital Data Package (DDP) • Cross-Discipline Lifecycle Collaboration (CDLC) • ReqIF WF	• CORBA • CWM (Common Warehouse Metamodel) • DDS • Model Driven Architecture • Meta-Object Facility • SysML • UML	• Complex Systems • Digital Engineering Information Exchange Working Group • MBSE Initiative • MBSE Patterns • System of Systems	• Formalization of Modeling (MF, German "Modellierung formalisieren") • Model based Systems Engineering (MBSE) • System Safety Modelling Language (Sys(S)ML) • Viewpoints

Table 2 – Working Group to consider for cooperation

2.5 Benefits, Challenges and Deployment of MBSE

Having introduced JT and MBSE, some benefits, challenges and the current deployment of MBSE shall be summarized. Some major benefits of MBSE are:

- Handling of complex systems and SoS
- Working inside a singe-source-of-truth that is constantly updated
- Early validation and verification as well as
- An easier communication between the different domains

Challenges are mainly based on the understanding of systems as a whole instead of the currently widespread component-oriented view. Therefore, some mayor challenges are:

- Organizational change process
- Enable employees to think functional and more user-oriented instead physical and based on existing products
- System-wide thinking and considering interfacing domains instead of focusing on the own domain

The current deployment is mainly set in the requirements phase on system level and refining of these requirements in the individual sub-levels. Some companies have started approaches for an overall MBSE approach, some start implementing sub-aspects of the MBSE approach, such as the functional decomposition. Especially the automotive domain is considering the MBSE methods due to some regulatory affairs.

3 Use cases of JT in context of MBSE

Based in these information regarding MBSE and JT as well as its respective formats, different use cases shall be presented, that are currently possible and can easily be implemented into the current tools and processes as well as use cases that need further research and investigation, but should be kept in mind and be supported by industrial companies. The presented use cases are:

- Current use case 1 – Visualization of model elements
- Current use case 2 – Model-based design and verification
- Current use case 3 – System information container
- Current use case 4 – Smart Hybrid Prototyping (SHP)

- Possible future use case 1 – JT as standard visualization format in SysML v2
- Possible future use case 2 – Bidirectional system model communication
- Possible future use case 3 – visualization of system model information in AR/VR
- Possible future use case 4 – parametric interaction with the system model

3.1 Currently possible usage of JT in MBSE

The most common usage of JT in a MBSE process is currently in the domain specific design phase.

The current SysML standard 1.6 does not include any stereotype or diagram type supporting 3D models, officially. The connection of the 3D visualization and an overall system model relies solely on software vendors.

Current use case 1 – Visualization of model elements: To connect the 3D components with the system model most software vendors offer a functionality to connect the system architecture as part of the system model with their product/system structure in the product data management (PDM) or even product lifecycle management (PLM) tool. PTC for example offers the possibility to export the system architecture from its modeling tool and import it in Windchill as product structure. As of the current build (Integrity Modeler 9.1) attributes as block-properties are not transferred with their respective blocks. Inside of the PDM tool, the 3D models can be linked with the system structure. This offers a better understanding of the solutions design for all stakeholders and offers a good starting point for further communication.

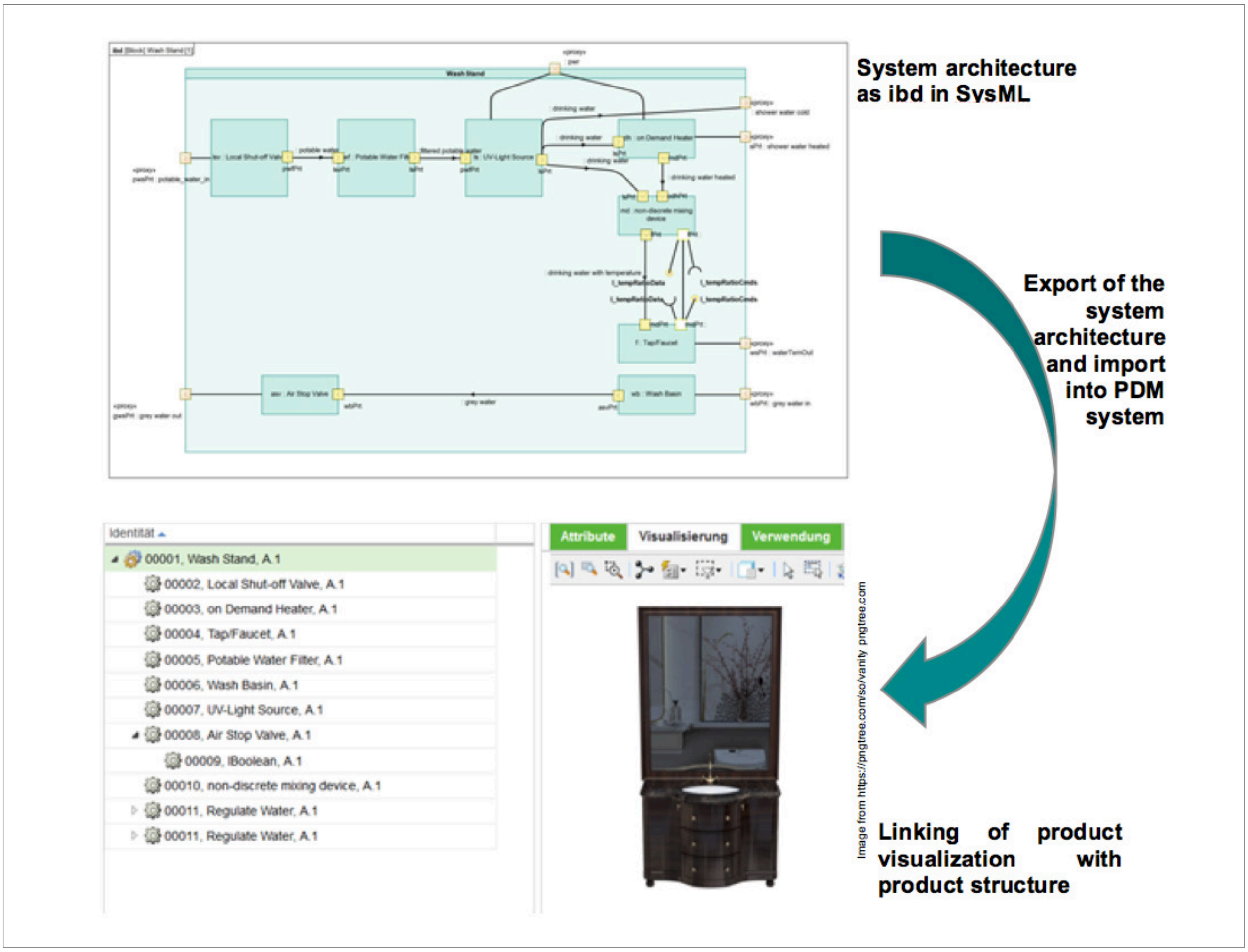

Figure 7: current use case 1 – Visualization of model elements in PLM/PDM system

With requirements management the same procedure is possible. Each requirement can be linked to a specific part and thus be evaluated on a 3D representation of its fulfilling component inside the PDM system.

Current use case 2 – Model-based design and verification: Beside the usage of SysML the 3D visualization can be used to directly express the advantages of MBSE. The top three use cases of Figure 2, "Documentation and Specification", "Communication" and "Interface Definition", can be realized directly on the 3D visualization A Design Engineer or a supplier could take for example a JT file as starting point and define relevant dimensions for the desired component. If these dimensions are attached as PMI's the inspector can use them later on directly for the CAQ comparison against a 3D scanned component.

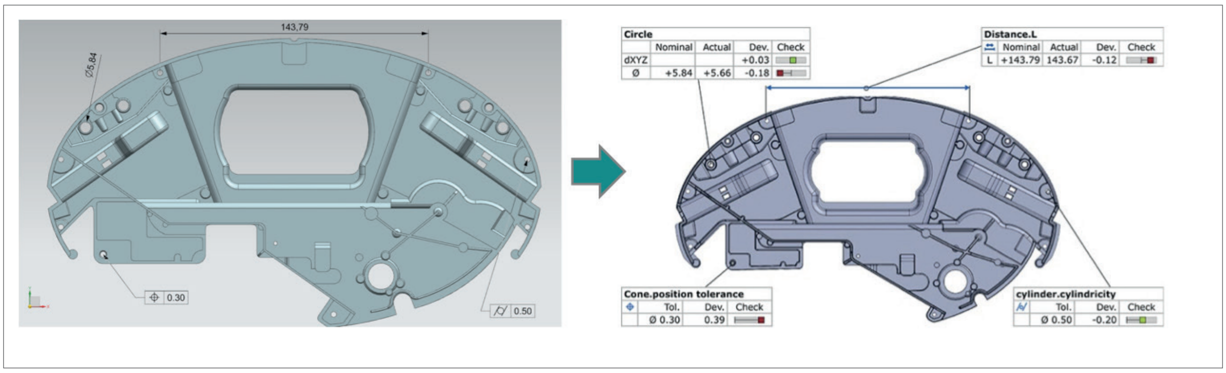

Figure 8: current use case 2 – model-based design and verification shown as CAQ based on PMI in GOM Inspect (GOM GmbH)

Current use case 3 - System's information container: The JT file in the figure above is holding the information instead of an overall system model. As MBSE does not mean, that a system model has to be modeled in a specific language, the usage of the JT file in combination with other information as AP242 XML as system model can also be seen as sufficient. This usage of JT as an information container can also be applied in other areas. In the Design phase can it be used to store information of different stakeholders in a virtual Design Review. Information can be attached in VR onto the component and be used as basis for further requirement refinements and design or functionality changes.

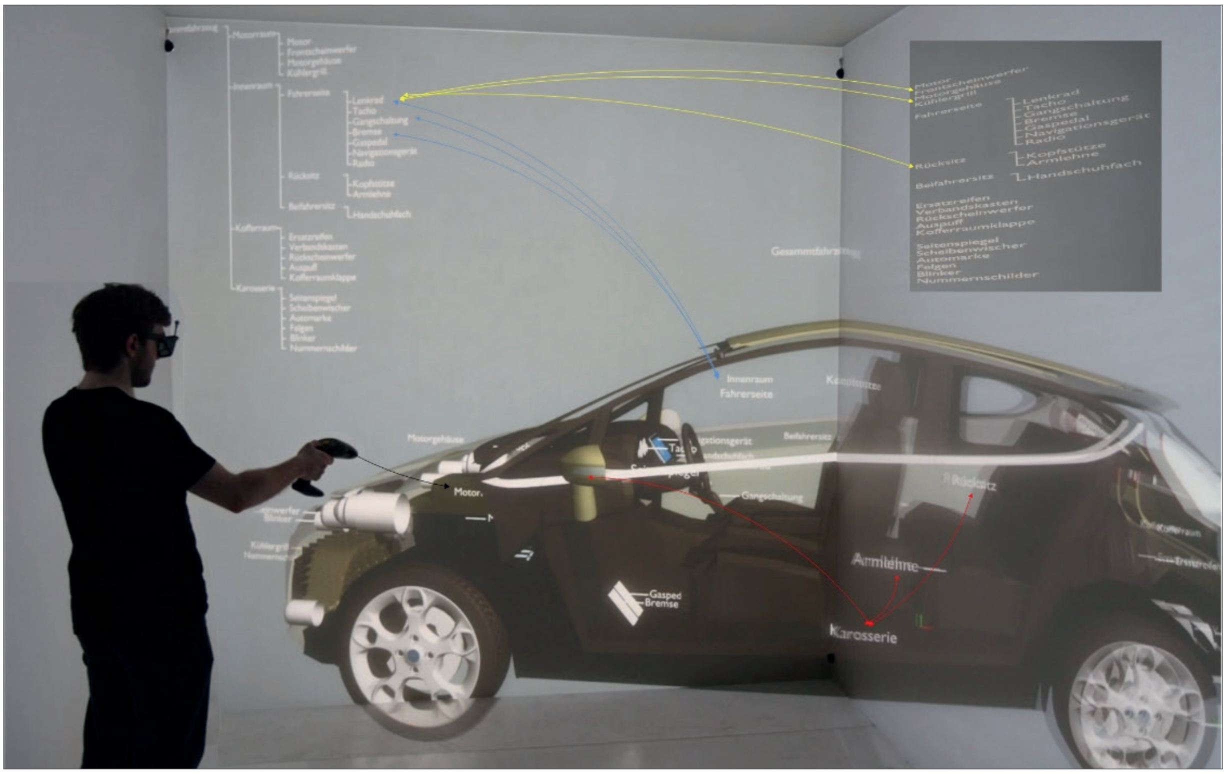

Figure 9: current use case 3 – system information container – Visualization of information on the 3D component (by Brandenburg – Fraunhofer IPK, 2019)

Current use case 4 – Smart Hybrid Prototyping (SHP): Another current use case is Smart Hybrid Prototyping (SHP), which can be seen as part of the right side of the V-Model in Figure 1. This is a methodology to develop mechanical and mechatronic systems where physical and digital components are combined to experience the functionalities of the developed product in the early phase of the development process (Becker et al. 2018, p. 124). It can combine Simulation, Visualization, PLM, Enterprise Resource Planing (ERP), CAD and many more systems. Some of these systems already use JT as visualization format, like Beckmann-Dobrev et al. have shown, while others currently rely on native CAD formats for the visualization. JT can be very useful due to its small size and independence of a CAD system. SHP allows a better understanding of the system as well as an early customer integration and better communication with other stakeholders.

Figure 10: current use case 4 – SHP – example of SHP test of back door (right, (Beckmann-Dobrev et al. 2010, p 7))

Other industrial applications are hard to find, as many companies want their applications not to be published to keep their advantage on the market. There are no common Key Performance Indicators (KPIs) found until now, to measure the outcome of these methods, but most companies testing MBSE methods say that they are capable of approaches they could not have taken without MBSE.

3.2 Use cases that should be considered

Beside the presented already productive use cases there are multiple potential use cases which might need some further investigation but are promising for the usage of 3D visualization.

Possible future use case 1 – JT as standard visualization format in SysML v2: As presented in the SysML v2 Roadmap, the RFP aims for the integration of geometric information. "RML 1.2: Model Libraries Proposals for SysML v2 may include Model Libraries that contain generic elements that can be further specialized to define domain specific libraries in the following domain areas: [...] Basic geometric shapes [...]" (Object Management Group, p. 70). This RFP shows, that geometric information like 3D visualizations are of general interest and will be better integrated into later MBSE methods. If the communities work closely together and support each other, JT could be the future format for visualization in SysML. Weilkiens mentioned that "SysML v2 may include a capability to represent basic two- and three-dimensional geometry of a structural element, including a base coordinate frame." (Weilkiens 2019). It is conceivable that stereotypes or profiles will be created which can be adopted or supported in development for the usage of JT.

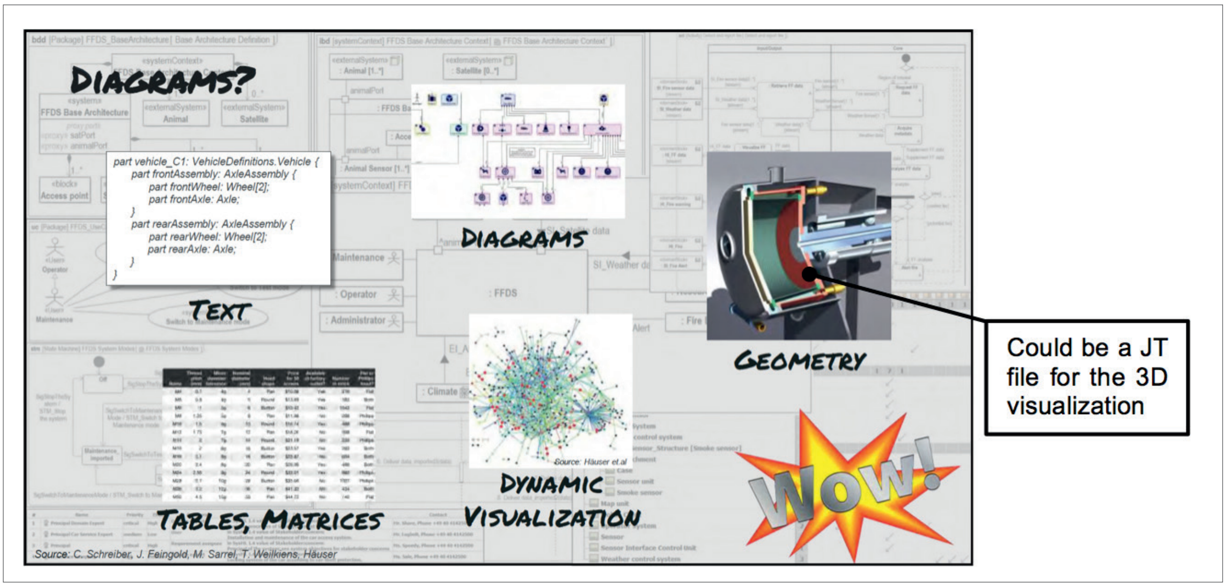

Figure 11: future use case 1 – JT as standard visualization format in SysML v2, graphic from (Weilkiens 2019, p. 23)

Possible future use case 2 – Bidirectional system model communication: Independent of the further specification of SysML it would be an important use case to extract parameters of the 3D visualization (in JT they are called properties) into the systems model or the adaption of these parameters based on information of the system model. This means, that the JT Open Toolkit, which is an API that offers reading and writing access to JT files, or other APIs should include other valid formats to exchange data. One approach of SysML is the XMI format, which is based on the XML standard and thus should be good to adopt. STEP AP242 XML should be tried to handle similar to XMI to interact with the overall system model.

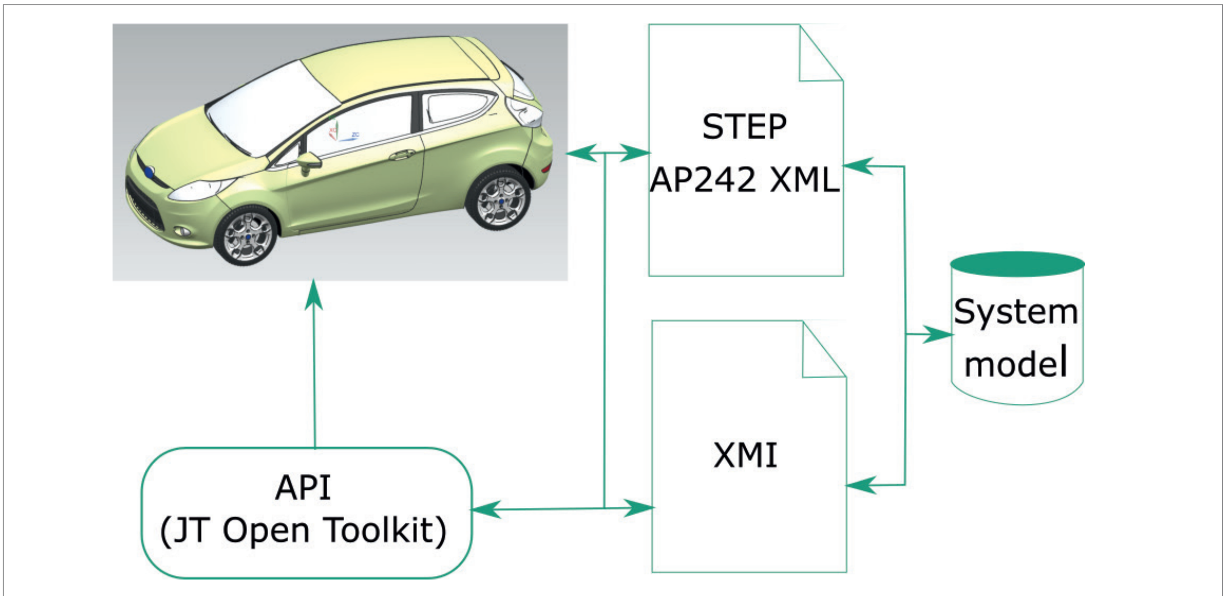

Figure 12: future use case 2 – bidirectional system communication – reading and writing of JT files from and to AP242 XML as well as XMI to interact with the system model

Possible future use case 3 - visualization of system model information in AR/VR: Another use case is the visualization of system model information, like the interfacing components, the interfaces themselves, constraints and requirements, or functions that are allocated to this structure e.g. in form of the SysML blocks. This means that as first step the information have to be includable into the JT file, including information on where they are allocated. Diota uses a self-developed software to process information together with a CAD file to visualize some instructions and information in an AR application at the physical component. JT could be used for similar use case to store the information such that different applications could access them and edit them for a better consistency.

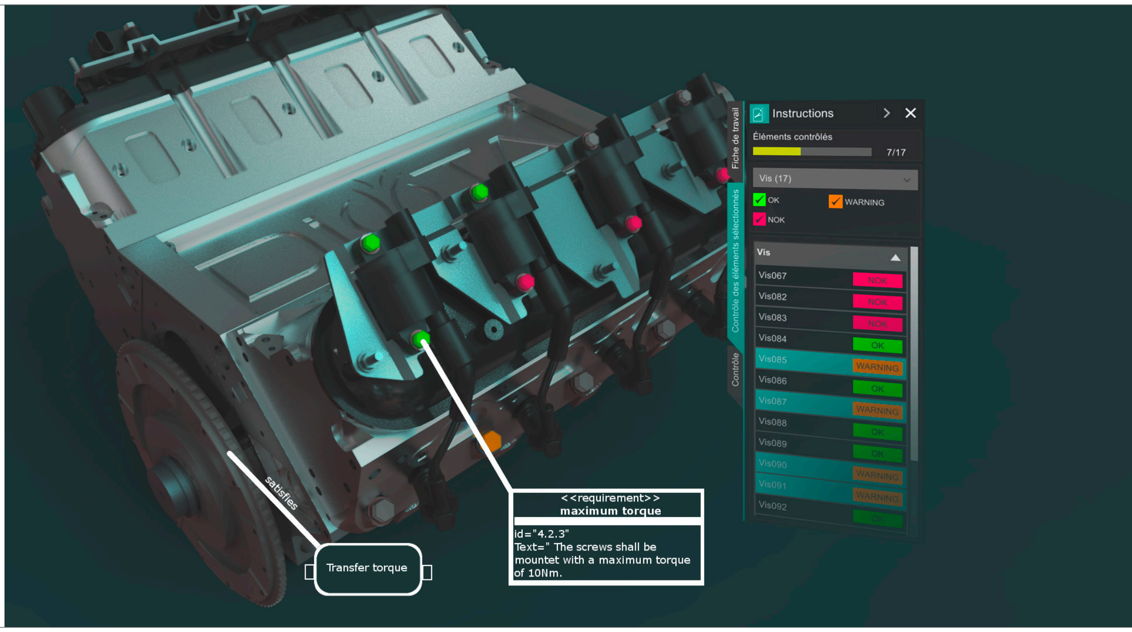

Figure 13: future use case 3 – system information visualization (adapted from (Diota 2019))

Possible future use case 4 - parametric interaction with the system model: When a graphical system architecture exists, no matter in which language it is written, the interaction with this system architecture should be supported. An easy example is the existence of a 3D visualization for a complete system, which adapts based on the system architecture. If a requirement for a diameter changes in the system model, this should influence the visualization by comparing the information to the existing part parameters, and highlighting non-compliance by changing the color or attaching notes. A direct integration of the changed parameters inside of the visualization is conceivable as well. Another case is the usage of AR/VR technology to resize, annotate and adapt components, which shall be imported into the system model. This requires a bidirectional communication of JT file and system model as well as a parametric visualization of the components, to such extend that the 3D form adapts to changes in the system model.

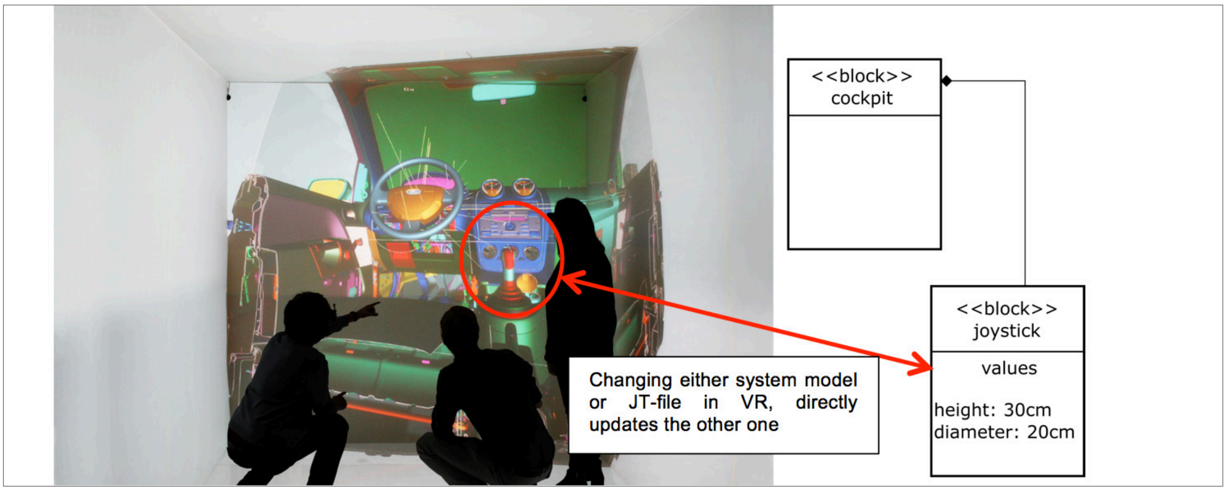

Figure 14: future use case 4 – parametric interaction with system model-changing components in VR directly induces a change in the system model and vice versa (Image adopted from IIT TU Berlin)

4 Summary and Recommendations

The goal of this paper has been to point out the current and future role of 3D visualization in MBSE with a major focus on JT as standard format for 3D visualization.

After an overview of MBSE and showing that MBSE is not only modelling a system architecture in a language like SysML, but the usage of models to support the SE approach, multiple use cases have been presented, where JT could be used as main model or as connected model to visualize some chosen information.

Based on these use cases possible future use cases have been presented. They should show which potentials the usage of 3D visualization in MBSE could have.

The main aspects focus on points of Figure 2:

- **Documentation & Specification:** JT can be used as a valid instrument for documentation and specification, as can be seen in the current use cases 1 to 3 as well as future use cases 1 and 3.
- **Communication:** Due to the easy usage of the documented information, all of the above use cases apply to communication as well. Additionally, the interdisciplinary communication is a very important aspect. Coping with the function and system thinking is difficult, especially for mechanical engineers. They can be supported in understanding what their colleagues from other domains demand and offer them by seeing it visualized in a known form as 3D components.
- **Interface Definition:** Interfaces could be defined directly on the JT file AR or VR in the future or visualized at the component, as seen in Figure 13.
- **Dynamic Behavior Modeling:** JT is not actively used for dynamic behavior modeling, but can visualize the behavior for example in SHP as seen in Current use case 4.
- **Impact Analysis:** An impact analysis might be supported by the visualization, e.g. in SHP, but is not likely to be performed mainly by JT files.
- **Derivation of Test Cases:** Test cases are mainly derived from requirements, which could be visualized next to the component and then manually derived. The documentation of the derived test cases may then again be presented on the model as seen in future use case 4.
- **Risk Analysis and Source Coding:** A risk analysis might be performed with SHP from use case 4 as well, but a full risk analysis or source coding are not imaginable part of the MBSE methods supported by 3D visualization.

Beside these aspects, JT is a comfortable form of presenting information to anyone integrated in a project. Thus, it should be further integrated into current MBSE approaches, as it can improve the the communication between different stakeholders and thereby support the acceptance of transformations to MBSE processes.

Considering these current and possible use cases some recommendations for Research and Development are:

Research Recommendations

Research Recommendation 1: At first, collaborations with the prostep ivip as well as OMG, INCOSE and GfSE working groups should be considered, based on the focus of their own work. The potential of a larger group with focus on a common goal can leverage synergies. As example for a combined goal the "Seamless Collaboration Demonstrator Mars Rover" from prostep ivip e.V. can be mentioned.

Research Recommendation 2: Second, the new SysML v2 should be investigated and potential synergies discussed with the respective working group. Recent presentation of the RFP Submission team (e.g. (Weilkiens 2019)) propose an API to interact with the models as well a 3D visualization of the model elements inside of SysML. As JT is a very compact format with different LOD and an open and standardized format it would be a good choice for this visualization.

Research Recommendation 3: The SysML WF sees XMI as the current standard for SysML model exchange. The interaction with this format should be considered as it is supported by most tool vendors supporting system modelling and is built upon XML, which is often used to share information associated with JT files, e.g. STEP AP242 XML.

Research Recommendation 4: The communication with tools is currently unidirectional or built as Export and Import functionality. Use Case 1 for example can only export the SysML structure to a PLM/PDM system and upload a JT component to it. This exchange should be bidirectional to allow JT writing and reading of model elements and such an even more immersive development.

Development Recommendations

Development Recommendation 1: Companies should focus more on developing their projects in modeling languages and connecting them with 3D geometric data, as this allows an easier communication and collaboration with different domains, industries and tools.

Development Recommendation 2: Starting in small projects it is beneficial to avoid drawings as much as possible and aim for a paperless-production and seamless product development. The communication from engineering to production can be performed with JT files assisted by PMI or AP242XML-data. This allows an easy understanding and the usage of the recent system-wide data.

Development Recommendation 3: As the employees are the most valuable part of a company and are the main source of innovation, they should be introduced to system-oriented thinking. As this is hard to understand coming from a component-based thinking, 3D visualizations in form of JT parts can support the understanding of this method. On the other hand, one can discuss with the engineers what functions a system fulfills by looking at the 3D-components. The system modeling can be supported in this way.

Finally, it has to be mentioned, that the 3D visualization will keep a leading role in Engineering and can support in many topics.

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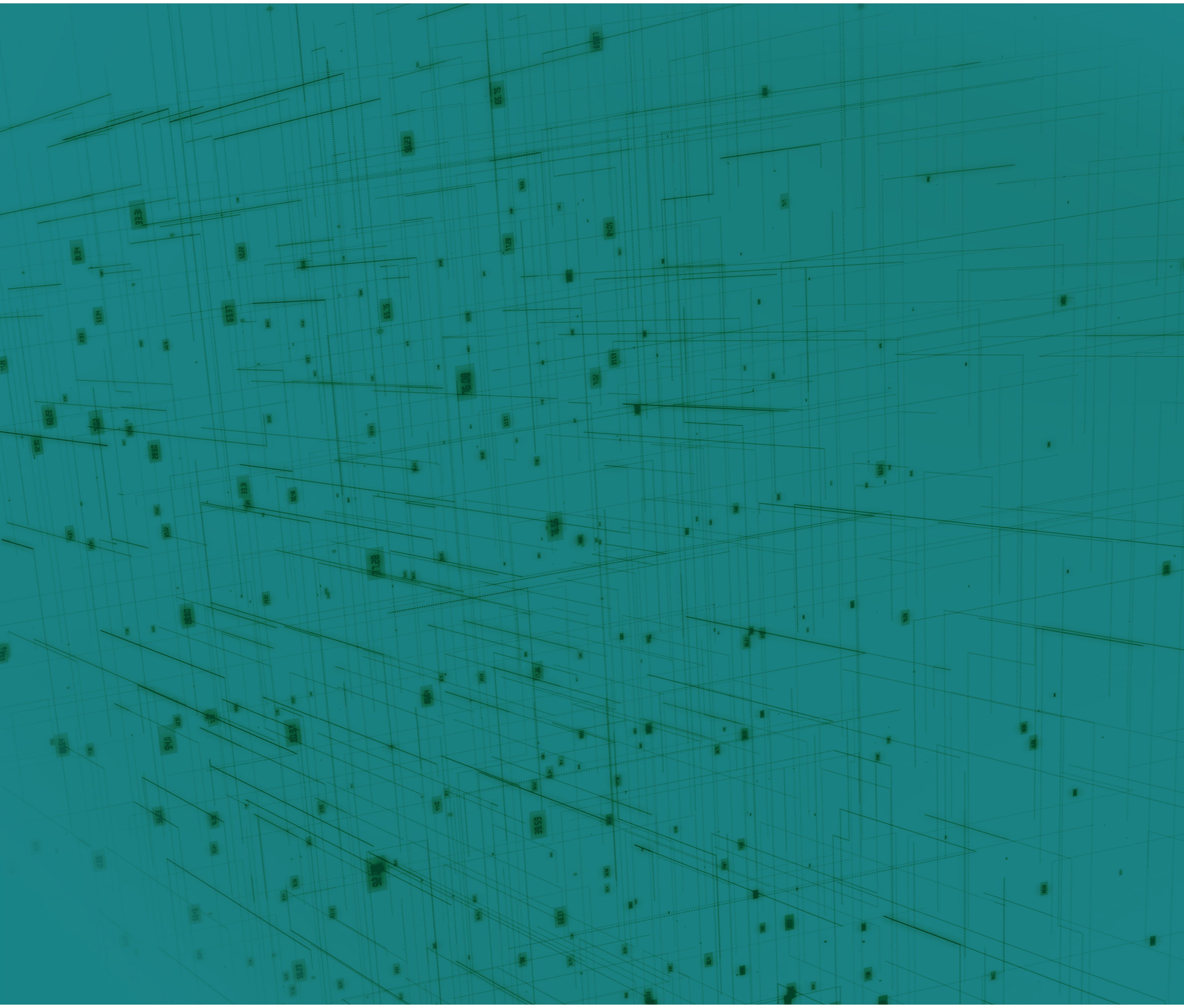

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