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Multimodel Framework for Digital Twin Empowerment

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Abstract

In recent years, digital twins have become a more significant strategic trend in the construction industry. Stakeholders in the industry view it as a technology-driven innovation that has the potential to support the design, building, and operation of constructed assets, alongside advancements in other new-generation information technologies such as the Internet of Things (IoT), artificial intelligence (AI), big data, cloud computing, and edge computing. However, the construction project context generates various organizational and functional information through model-based domain-specific information models that require integration and analysis. Furthermore, commercial technologies enable the integration of real-time data sources with building information models (BIM), but these tools are often proprietary and incompatible with other applications. This lack of interoperability among heterogeneous data formats is a major obstacle to the reliable application of digital twins in the construction industry. To address this challenge, this study presents a multimodel framework developed using Information Container for Linked Document Delivery (ICDD) that can integrate multiple data models from autonomous and heterogeneous sources, including real-time data sources, in their original format at the system level. This framework enables stakeholders to analyze, exchange, and share linked information among the built asset stakeholders, relying on linked data and Semantic Web technologies.

Keywords: BIM; Multimodel; Digital Twin; Linked data; Information Containers

Introduction

Since two decades ago, when the concept of "digital twin" was first proposed by Dr. Michael Grieves, NASA coined the definition and function of it in 2010 [1]. Since then, with the emergence of new technologies, various industry sectors have been leveraging this concept in product manufacturing to optimize the operation and maintenance of physical assets, systems, and processes [2]. Increasingly, industries are shifting towards a smart manufacturing paradigm with multi-scale dynamic modeling, simulation, and intelligent decision-making. The collaboration and integration of advanced technologies such as building information modeling, artificial intelligence, and wireless networks into digital twins are becoming more prominent in the architecture, engineering, and construction industries. Digital twins are offered as a new technology-driven innovation to support the design, building, and operation of constructed assets [3].

On the one hand, BIM provides techniques, tools, and data schemas that allow for standardized semantic representation and systems. By utilizing real data, the digital twin enables the visualization, monitoring, and optimization of operational assets, processes, and resources that provide crucial, real-time information on performance and activity. On the other hand, BIM lacks semantic completeness in areas such as control systems, including sensor networks, social systems, and urban objects outside the scope of buildings, necessitating a holistic, scalable semantic approach that considers dynamic data at several levels [4]. Modern high-performance buildings have sophisticated monitoring systems and sensors installed to collect large amounts of data on their indoor environmental quality and energy usage that can be used to enhance their overall performance [5].

However, construction projects are unique endeavors in terms of project design, organization, and production facilities and processes. They are distinguished by many stakeholders, which has historically made it difficult to develop integrated information systems [6]. Although BIM applications have significantly improved architecture, engineering, and construction since they allow specialists to model all building design information into one three-dimensional BIM model, including 3D geometry, cost information, material information, etc. To contribute to overall industry collaboration, the Industry Foundation Classes (IFC) schema was released almost three decades ago as an open and neutral data structure for saving digital building descriptions and serves as a global standard for BIM data interchange. However, a single IFC file containing fundamental object information is insufficient for resourceful decision-making [7]. On the other hand, various model-based, domain-specific information models generate the building models, leaving the BIM lacking in terms of interoperability and automation. This poses a serious challenge for the development of a comprehensive construction digital twin. Model interoperability requirements have been partially met by commercial vendors, which facilitate seamless integration through import and export capabilities among BIM tools. However, in time, the number of tools and platforms shared among project actors can quickly become overwhelming [4].

Given these shortcomings and relying on Semantic Web technologies, this study presents a multimodel framework developed based on the ICDD standard ISO 21597 to integrate multiple data models, in their original format, from autonomous and heterogeneous sources, including real-time data sources, at their system-level and enables analyzing, exchanging, and sharing this linked information among the stakeholders of built assets. The framework aims to provide an information container that contains holistic linked information not only about a built asset itself but also about all related information sources throughout its lifecycle to enable more reliable decision-making and built asset management. This research is the first step towards developing a holistic, dynamic multimodel framework to link all related data models to the building model while evolving over the building lifecycle, starting from the conceptual design, passing through the construction phase, and ending with facility management.

Semantic Web Technologies for Digital Twin

The construction industry has greatly benefited from the implementation of digitalization, with Building Information Modeling (BIM) being a significant contributor. BIM was initially designed for the exchange of documents in proprietary formats using the Industry Foundation Classes (IFC) and has since evolved to encompass the management of built assets throughout their life cycle. However, BIM's current state is not entirely compatible with the integration of the Internet of Things (IoT) due to its legacy formats and standards, which restrict its capabilities in a Semantic Web environment [8]. Nevertheless, the emergence of web technologies such as RDF, OWL, and SPARQL offers the potential for a dataand web-based BIM paradigm, which is becoming increasingly viable. Due to its ability to enhance both interoperability and collaboration between disciplines, and its significant impact, the application of Semantic Web and Linked Data concepts in the AECO industry has already been extensively studied [9]. Pauwels argued that building data can be structured using Semantic Web technologies, which can facilitate interoperability and enable logical inferences and proofs. This has numerous benefits for the industry, including lossless data exchange and fully integrated systems [10]. Research by Abanda et al. [11] provides an in-depth overview of the trends in ontology and semantic web linked data over the last decade. The study highlights growing interest in the application of these technologies in the fields of risk analysis, project management knowledge sharing, and energy performance analysis, particularly in the construction sector.

One of the key benefits of using the Semantic Web and linked data is their ability to promote interoperability between various application domains, enabling seamless data exchange and collaboration [11]. Semantic Web technologies have the potential to greatly facilitate the integration of data from the AECO domain with data from other domains. One example of this is the use of geographic information systems (GIS) throughout the various stages of civil infrastructure projects. Over the past ten to fifteen years, the GIS community has increasingly turned to web and semantic web technologies. This shift has led to a greater abundance of GIS data available on the web, resulting in improved accessibility and usability of this data. By leveraging Semantic Web technologies, GIS data can be more easily integrated with other types of data from different domains, enabling more comprehensive analyses and informed decision-making [12].

An accurate Digital Twin (DT) model means data from diverse fields, such as dynamics, structural mechanics, acoustics, thermals, electromagnetics, materials science, control theory, and sensing and measurement technologies, should be integrated into the virtual space to make the models more accurate and closer to reality.

The adoption of Semantic Web technologies has been identified as a promising approach to improving interoperability in the AEC sectors, resulting in a more integrated and efficient data exchange environment. These technologies enable the description of information in a format that can be easily understood by computers. In addition, Semantic Web technologies enable the linking of data from multiple domains, such as BIM, GIS, heritage, sensor data, simulation data, and smart cities, into a single web of linked building data. This approach facilitates better collaboration and data sharing among stakeholders involved in the construction industry, leading to improved project outcomes and overall efficiency [12, 13].

Approach

Compared to the manufacturing field, the construction industry consists of large groups of independent components, including designers, consultants, contractors, suppliers, and public agencies. These groups pass through different stages, resulting in complex interdependencies. Construction is an evolving system that develops every day through variations and developments in its physical structure, making it complex and not easily understood or predicted by an automated system. Given these challenges, we propose a dynamic multimodel-based approach for the implementation of a real-time data digital twin. First, we present the multimodel concept, then we propose the implementation framework.

Multimodel concept

Architects, engineers, and construction professionals are increasingly using sophisticated computational models to address the behavior of multiple features and elements in the built environment at various levels of resolution and across different disciplinary domains. The basic idea of a multimodel is to combine distributed application models, or selected views of them, in a single exchangeable information resource. Within the resource, the application models are bound together by link models that explicitly specify the interdependencies among the application models, referencing the respective model elements by their identifier (ID). The resulting compound model represents a logical business object reflecting the results of a certain business activity, which can be stored in a persistent data store or serialized in a multimodel container.

The multimodel approach is a viable way to support information analysis and collaborative work across multiple application domains. It allows for joining discrete information from different software applications to inspect the coherence of related application models and create complementary analysis models. Instead of relying on the all-in-one model approach to achieve interoperability, the multimodel approach respects the individual application models maintained by different domain experts. Interoperability should be accomplished on demand in different software applications and supported by ontologies [6].

The combination of application models in multimodels provides a basis for a general methodology to interrelate, compare, analyze, and reuse any kind of information throughout construction projects. Using the multimodel approach outlined by [14], which enables connecting the domain models to a multimodel to perform cross-domain tasks formalized as a multimodel container (MMC), stakeholders can exchange and share linked information among themselves. The multimodel also enables filtering, querying, and reasoning among the models, along with the benefit of a shared data environment. This strategy also avoids the need to modify the linked models, which is crucial for standardized data models like the IFC.

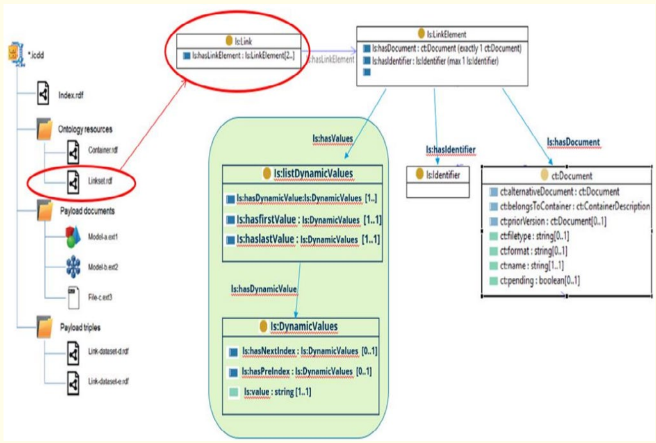

Figure 1: Structure of ICDD container (the extended schema highlighted in green) [18].

Combining the Linked Building Data (LBD) approach with the multimodel approach, the ISO 21597 [15] enables an environment for the integration and reasoning of data on the Web, as well as dynamic semantics through ontology-based link model extensions. The ICDD provides structures and methods for the inter-linkage of heterogeneous data and their exchange between different applications as a closed solution to an engineering problem [16]. The standard specifies a container that stores documents and links otherwise disconnected data within those documents. The container of *.iccd format (compressed with ZIP) has a fixed structure, consisting of the relevant linked models and documents in a Payload Document folder and the linked models in a Payload Triples folder. Each container has an index file that specifies its content, based on the concept of the multimodel approach [16]. The index file and the Link Model schemas are defined in Part 1 of the standard via the two ontologies Container.rdf and LinkSet.rdf [10]. The internal structure of the ICDD comprises two ontologies: a container ontology, which defines the classes and properties used for the description of metadata about the container, and the linkset ontology, which provides the definitions for the semantic links between documents. Fig. 1 illustrates the structure of an ICDD container on the left, sourced from ISO 21597-1, and the extended ICDD framework on the right, which was developed by Al-Sadoon, N. to enable dynamicity for building elements. The Linkset ontology is extended so that multiple values could be explicitly allocated for any building element [17, 18].

Multimodel based approach

Optimizing the value of data can be achieved by implementing a well-designed framework, which facilitates a deeper understanding of performance data and highlights its true potential. To this end, we have developed a multimodel engine (MME), as depicted in Fig. 2, utilizing a multimodel approach. The engine is designed as a microservice, allowing for seamless communication with other applications and integration into cloud-based software via REST (Representational State Transfer) interfaces. The MME is equipped with several functionalities to accomplish the research objectives, including:

1. Create the multimodel container (MMC) based on the object classes and properties provided by the Container.rdf ontology that

specify the contents of the container.

2. Add documents, which include all building information models and data sources. These documents could be internal or external (both added in their original format).
3. Perform a filtering function based on the end user requirements on the documents and elements within them.
4. Create links between the documents or objects within them based on the Linkset.rdf ontology.
5. Based on the extended dynamic ICDD [18], additional functionality was developed to enable the explicit assignment of multiple states to any building element.

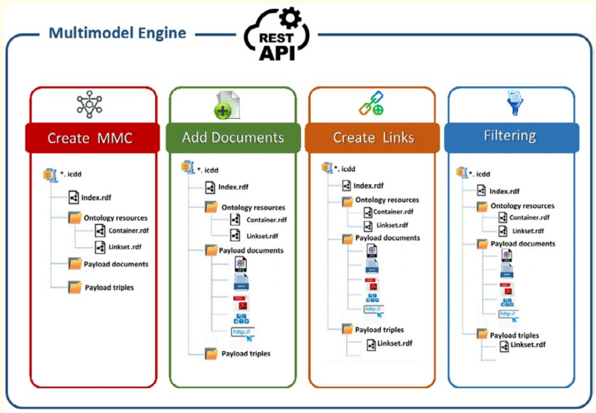

Figure 2: Multimodel engine main functionalities.

As a shared data environment, the creation of a multimodel container in the form of *.icdd allows for searching, querying, and reasoning across various documents. It is worth noting that the construction industry is a constantly evolving field, and therefore, the versioning functionality [19] is a crucial feature. This will enable the versioning of documents and automatic updates of corresponding Linksets. The multimodel approach offers a standardized structure for loosely coupling heterogeneous data models, while the multimodel engine functionality provides a common environment for models, elements, and values. As a result, this approach adds value to the information and provides a comprehensive digital twin for the industry.

Approach verification

To verify the proposed approach, an exemplary use case is carried out here. As a test case, a BIM model for building NUR31 on the Technische Universität Dresden campus is created using Autodesk Revit. It contains the building geometry and other building-relevant information. The 2nd floor of the building, where the Institute of Construction Informatics is located, is equipped with sensors to measure temperature and air quality, in addition to a weather sensor to gather outdoor environmental data. The approach is formalized by creating the multimodel engine using Python, OwlReady2, and SQLite. For validation, a prototype for a web-based graphical user interface application, currently under development, will be made available for the end-user to implement the multimodel engine functionalities. REST APIs are created to implement these functionalities. To test the APIs, the Postman application was chosen. In the following paragraphs, we describe how the implementation is carried out.

As stated in the research objective, the integration of multidisciplinary application models in their original formats from diverse sources, including real-time data sources at a system level, is proposed. The data model sources selected for integration into a Multidisciplinary Model Container (MMC) are from various domains, including sensors, web resources, and BIM model data. To establish the relationships between documents and their elements, the ICDD standard offers two main types of linking: ls:BinaryLink and ls:DirectedLink. The ls:Directed1toNLink, which is a subtype of the ls:DirectedLink, is the linking type used for implementation here. This type provides the mechanism to link one data model (or element from it) with multiple data models (or elements inside them). The main data model is the NUR31 building model in IFC format, while the other data models will be:

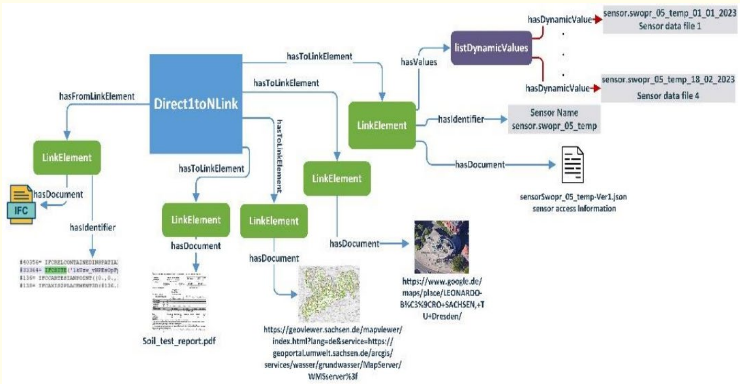

Figure 3: Linking multiple data sources to a single building element (1 to N Link).

1. Real-time data model from weather sensor.
2. Water Ground level at the site location as an Environmental model (GIS URL).
3. 2D Floor plan at level 2 NUR31 building as a JPG file.
4. Soil Geotechnical Report as a PDF file.
5. And URL for the building location on google map.

The multimodel engine functionalities progress as follows: First, the MMC is created, and then the data models mentioned above are uploaded into the container. It's worth mentioning here that the ICDD standard provides the specification to add the data models either to be uploaded and saved in the container or to define the corresponding URL (such as web resources) where the external data model is located. The next step is to create the links. We propose here that the end-user wants to link an element from the building model, which is the IfcSite, with the other data models. So, when the end-user implements the linking function, he must select the IfcSite element from the BIM model. Based on their selection, the multimodel engine will perform a filtering function in the IFC file to determine the GUID of the IfcSite element and assign it as hasFromLinkElement. Then the hasToLinkElement is defined accordingly by selecting the other data model, as shown in Fig. 3.

To increase efficiency and provide a more valuable In the multimodel container, additional functionality was added to access the sensor to retrieve sensor data and then save it in the Payload documents as a *.csv data model. Fig. 5 illustrates the implementation of this function to retrieve weather sensor data for the period from January 1 to January 31, 2023. This process is repeated based on the end-user requirements. For example, here we retrieve four different weather sensor data sets. As these four datasets belong to a particular sensor, therefore, the extended Linkset.rdf ontology developed in [18] is adopted to add the aggregated sensor data models as multiple values within the listDynamicValues of the document folder 'sensor.swopr_05_temp.' as shown in Fig. 4.

It's worth noting that utilizing the listDynamicValues feature can allow for the creation of multiple files that contain aggregated data for each sensor. This approach enables the retrieval and storage of sensor data based on the anticipated usage by the end-user. After creating the multimodel container, adding the data models, and creating links, the container is ready to be shared, exchanged, and provides the capability to perform the functionalities of searching, querying, and reasoning across the documents based on domain-specific requirements. Fig. 6 shows an example of retrieving linked data from the multimodel container.

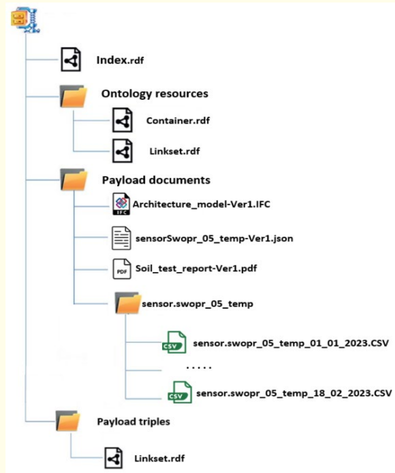

Figure 4: ICDD structure for verification use case.

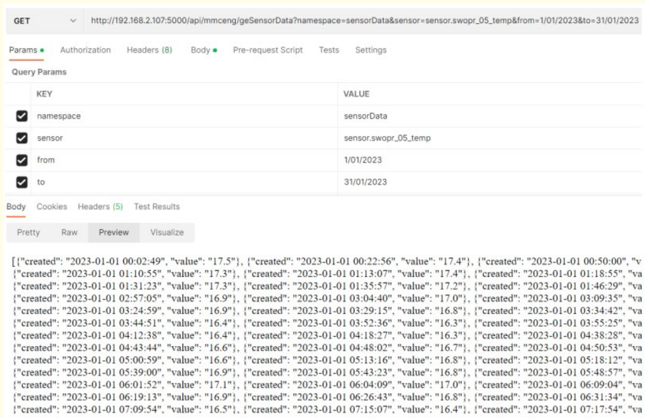

Figure 5: API for sensor data retrieving.

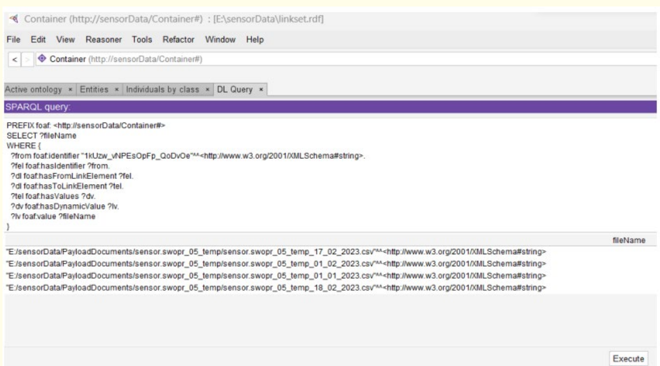

Figure 6: Querying weather sensor files linked to IFC site.

Conclusion and future work

As architects, engineers, and contractors adopt the new generation of information technologies at a rapid pace, the demands for collaboration and coordination are increasing, resulting in an enormous amount of information and multiple fragmented data models. Thus, in order to fully utilize this information and manipulate it throughout the building lifecycle to create and maintain digital twins, this study proposes the multimodel approach to link all distributed data models that could be produced from design to decommissioning. The developed dynamic multimodel framework allows the correlation of data generated from heterogeneous sources (tools, sensors, buildings, etc.) with BIM models on an object level while maintaining the format of the original data sources. By doing so, it sets up a holistic knowledge base of semantically linked information that can be deployed by machine learning, deep learning, data mining, and analysis capabilities to support holistic decision-making. An experimental use case has been implemented for an existing building as part of the evaluation of the proposed approach, which is planned to support web-based advanced smart services for digital twin empowerment in the iECO [20] research project. Further development in future work will be to create a common platform to connect building information models with readily available data from multiple systems using the extended ICDD framework. This will assign multiple data sources to BIM elements and add versioning functionality that enables the versioning of the elementary models, particularly the BIM model, throughout the building lifecycle. Hence, developing such a dynamic ontology-based approach for linking BIM data with multiple data sources at the building element level aims to facilitate interaction between different datasets and provide the opportunity to perform evaluations across multiple systems, thus supporting smarter decisionmaking processes. This will undoubtedly pave the way for more reliable digital twins.

References

1. Grieves M. "Digital twin: manufacturing excellence through virtual factory replication". White paper 1 (2014): 1-7.
2. Boschert S and Rosen R. "Digital Twin-The Simulation Aspect "in Mechatronic Futures: Challenges and Solutions for Mechatronic Systems and their Designers". P. Hehenberger und D. Bradly, Hg (2016).
3. Kit KT. "Paradigm of Digital Twin Application in Project Management in Architecture, Engineering and Construction". International Journal of Civil and Architectural Engineering 16.4 (2022): 122-127.
4. Li CZ., et al. "The application of BIM in the AECO industry". Journal of Civil Engineering and Management 29.3 (2023): 202-222.
5. Kazado D, Kavgic M and Eskicioglu R. "Integrating building information modeling (BIM) and sensor technology for facility management". Journal of Information Technology in Construction (ITcon) 24.23 (2019): 440-458.
6. Scherer RJ and Schapke SE. "A distributed multi-model-based management information system for simulation and decision-making on construction projects". Advanced Engineering Informatics 25.4 (2011): 582-599.
7. Pan Y and Zhang L. "A BIM-data mining integrated digital twin framework for advanced project management". Automation in Construction 124 (2021): 103564.
8. Howell S and Rezgui Y. "Beyond BIM: Knowledge Management for a Smarter Future". IHS Markit (2018).
9. Beetz J, van Leeuwen JP and de Vries B. An ontology web language notation of the industry foundation classes. In Proceedings of the 22nd CIB W78 Conference on Information Technology in Construction, Technische Universität Dresden (2006): 670.
10. Pauwels P., et al. "Enhancing the ifcOWL ontology with an alternative representation for geometric data". Automation in Construction 80 (2017): 77-94.
11. FH Abanda, JHM Tah and R Keivani. "Trends in built environment Semantic Web applications: where are we today?"Expert Syst. Appl 40 (2013): 5563-5577.
12. Falquet G, Metral C and Cutting-Decelle AF. "Towards semantically enriched 3D city models: an ontology-based approach". Proceeding GeoWeb 2009 Academic Track-Cityscapes-International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences (2009): 40-45.
13. Pauwels P, Zhang S and Lee YC. "Semantic web technologies in AEC industry: A literature overview". Automation in construction 73 (2017): 145-165.
14. Fuchs S and Scherer RJ. "Multimodels—Instant nD-modeling using original data". Automation in Construction 75 (2017): 22-32.

15. International Standardization Organization. Information Containers for linked document delivery (2020).
16. Scherer RJ and Katranuschkov P. "Context capturing of multi-information resources for the data exchange in collaborative project environments". InProceedings of the European Conference on Computing in Construction (EC3 2019) (2019).
17. Al-Sadoon N and Scherer RJ. "IFC Semantic Extension for Dynamic Fire Safety Evacuation Simulation". InProc. of the Conference CIB W78 2021 (2021): 11-15.
18. Al-Sadoon N, Katranuschkov P and Scherer RJ. "Extending ICDD Implementation to a Dynamic Multimodel Framework". InProc. of the Conference ECPPM (2022).
19. Al-Sadoon N and Scherer RJ. "From Static to Dynamic Information Containers _ Dynamic ICDD". In Proc. of the Conference EC3 (2023).
20. IECO Consortium (2022).