



MATCHFEM: A COMPUTATIONAL DESIGN ASSISTANT TOOL FOR DIGITAL TWINS OF BUILDINGS AND INFRASTRUCTURE

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Abstract

Digital Twins (DT) has gained traction in recent years, offering significant potential to centralize design, construction and operation processes, improve management, and support decision-making. However, implementing DTs in the AECO sector involves managing various technologies and software, leading to increased complexity for professionals. This paper presents MatchFEM, a tool designed to simplify data generation for DTs within a unified environment. Developed as a plug-in for Grasshopper Computational Design (CD) software, MatchFEM facilitates 4D IFC-BIM modelling, IoT monitoring, data processing, and Structural Analysis models generation, key components of DTs. A case study is included to demonstrate its functionality and potential benefits.

Introduction

Digital Twin (DT) technology has gained considerable momentum in recent years, offering potential to gather construction processes and management practices in a central digital system. This system is constantly fed with data, thereby facilitating well-informed decision-making (Broo et al., 2023). In recent years, Building Information Modeling (BIM) has already been adopted in the sector with a high level of maturity, setting a precedent for advanced digital practices. The sophisticated implementation of BIM has paved the way for the potential success of DT by providing a solid foundation for data management and collaborative processes.

Despite their potential, the adoption of DTs in AECO (Architecture, Engineering, Construction and Operation) sector is hindered by several challenges. These include restructuring organizations and workflows to align with digital transformation objectives, bridging workforce skills gaps for effective information technology adoption, fostering a cultural shift within the workforce to embrace emerging technologies, ensuring the availability, quality, and preparation of data, achieving seamless interoperability across various data formats and technologies, and validating technological solutions through case studies to establish scalability, readiness, and deployment viability (Posada et al., 2024). Within this

context, the MatchFEM tool was conceived to streamline the preparation and generation of quality and structured data. Designed to promote interoperability across software systems, it also aims to bridge the gap in Information Technology (IT) skills needed for the implementation of DT technology.

MatchFEM is developed as a plug-in for the Rhino and Grasshopper (2025) Computational Design (CD) software using C# programming language. It harnesses its powerful geometrical engine and its parametric environment to allow users to construct efficient workflows and automate repetitive tasks using its intuitive visual programming interface. The tool assists in the preparation and generation of the following information components for DTs: BIM geometry and metadata based on the Industry Foundation Classes (IFC), Planning and Scheduling, Internet of Things (IoT) monitoring, Data processing and Structural Analysis models. The integration of additional components may be necessary for a multi-purpose DT; nevertheless, the aforementioned elements establish a comprehensive informational base. In addition, users can deal with these technologies in the same environment and without necessitating advanced IT skills.

This paper first introduces the background that underscores the need for this tool, establishing its relevance within the field. Subsequently, the development process of the plug-in is presented, followed by a description and analysis of its features, with a focus on their disruptive potential. Finally, a case study is included to provide a clearer understanding of its practical functionalities and benefits.

Background

DTs as central system assistants for the design, construction, maintenance and operation of built assets require the gathering of multiple sources of information generated by diverse stakeholders (Zhang et al., 2022). These sources rely on a variety of ITs. For instance, these ITs sources can be gathered in five DT conceptual layers: digital modelling, data acquisition, data transmission, data/model integration and services (Tuhaise et al. 2023). Specifically, these conceptual layers use technological enablers such as BIM, sensors, drones, laser scanners, Extended Reality, IoT, knowledge graph databases,

advanced data processing, Structural Analysis, Artificial Intelligence, among others. In the construction research field, a variety of DT applications have been developed using those technologies (Chacón et al., 2024; Kang et al., 2024; Pregolato et al., 2022).

The AECO sector has been traditionally slow in adapting to emerging technologies. One significant barrier is the reluctance of professionals to learn and adopt ITs or the lack of integrational ITs. BIM has been set for many years as the fundamental tool to enhance collaboration and productivity in the industry. Despite its widely recognized benefits, the lack of skilled experts remains a major obstacle to BIM adoption (Zahedi et al., 2022). Siddiqui et al. (2023) identified insufficient digital skills and limited collaboration as key barriers to technology adoption in construction. The study highlights the need for global networks and expanded research beyond BIM. It also introduces a taxonomy of digital skills applicable across various roles in the industry, encompassing automation and robotics, coding and programming, design and drafting, digital data acquisition and integration, digitization and virtualization, modeling and simulation, as well as planning and estimation. New skills also pose crucial needs for specialists in the new era of digitization (Posada et al 2024).

CD has also gained momentum within the AECO sector, supporting and enhancing design processes through algorithms, simulations, and data analysis. Popular software tools such as Dynamo, ArchiCAD, Grasshopper, and GenerativeComponents have been widely adopted for implementing CD techniques (Ma et al., 2021). Researchers have recognized this trend and developed numerous studies utilizing CD. For instance, Dervishaj (2023) proposed a digital framework integrating BIM and CD for urban and building design, organizing digital tools and indicators around the pillars of climate, people, and nature. Mowafy et al. (2023) developed a parametric BIM-based Lyfe Cycle Assessment (LCA) framework to assess material selection and quantify environmental impacts, incorporating Grasshopper and its Rhino.Inside.Revit plug-in to enrich BIM models with environmental data.

Other research highlights the integration of CD with industrial robotics and DTs. Anane et al. (2023) introduced a framework for using industrial robots in off-site construction, leveraging BIM for information management, Grasshopper for design and programming, and robotic manufacturing for execution. In tunneling projects, Getuli et al. (2021) developed a methodology combining BIM and Dynamo (2025) CD to generate as-built models on-demand, utilizing real-time data from Tunnel Boring Machines (TBM). Noronha et al. (2023) presented a workflow for generating accurate BIM models of historic buildings to support DTs. Their method uses a Grasshopper parametric script to create BIM objects of historic columns from point cloud data.

Given this background, MatchFEM was developed to meet the AECO sector's growing demand for digitization

by facilitating its adoption among professionals. It aims to promote DTs implementing CD to simplify workflows.

MatchFEM Development

The development of the plug-in emerged during Ashvin, a Horizon 2020 European project (Ashvin, 2024) in which recommendations connecting different simulations to BIM-based DTs were provided (Chacón et al, 2023a). As part of this initiative, the authors worked on a series of real-world demonstrators that were successfully twinned. These included the construction of an office building (Posada et al., 2024), the load testing of a high-speed railway bridge (Chacón et al., 2023b), and the maintenance inspections of a highway bridge (Chacón et al., 2023c). Figure 1 shows these three DTs demos.

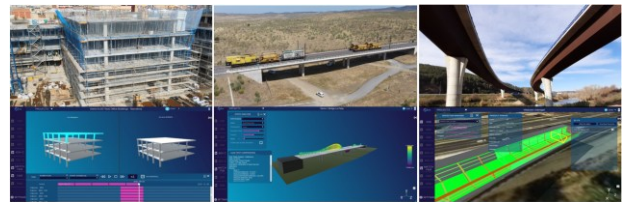


Figure 1: DTs demos developed by the authors: (Posada et al., 2024; Chacón et al., 2023b; Chacón et al., 2023c)

These demonstrators were developed integrating BIM, various data-capturing methods, structural simulations, knowledge graph databases, data processing, and decision-making tools. In each case, Grasshopper CD capabilities were utilized to interact with DT data within a parametric environment. Over time, the creation of custom scripts and components using C# programming language, evolved into a comprehensive plug-in (MatchFEM) consolidating features to address information needs for DTs.

The following section outlines the general features of the tool, highlighting its innovative and transformative potential.

MatchFEM General Features

MatchFEM is centered around five general features: (i) 3D BIM geometry and its metadata compliant with the IFC schema, (ii) planning and scheduling to create 4D BIM, (iii) setup of sensors and IoT for onsite monitoring, (iv) processing of sensor data, and (v) generation of interoperable Structural Analysis models. Each feature is described in detail below.

Geometry and Metadata

The IFC open schema is the most widely adopted standard for representing and describing the built environment. MatchFEM enables the creation of complex IFC geometries and semantically rich models by leveraging the NET open-source xBIM toolkit (2025). The *IfcShapeRepresentation* class supports a variety of geometry types, including points, surfaces, and solids. Using the plug-in, users can generate SweptSolids, Breps,

and *AdvancedBreps* directly from Grasshopper geometry (see Figure 2).

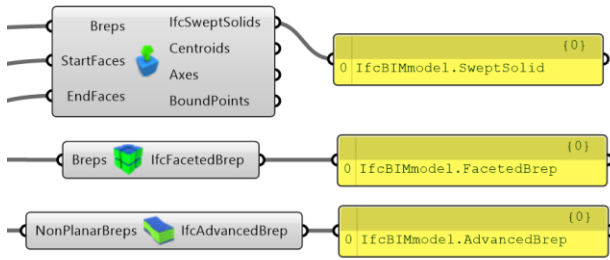


Figure 2: Generation of IFC geometries using MatchFEM (*SweptSolids*, *Breps* and *AdvancedBreps*)

When it comes to *AdvancedBreps*, it is noteworthy that this study identified that only a few applications are capable of processing them correctly. Most existing software resorts to tessellation and meshes to approximate the shapes of complex geometries, which results in significantly larger IFC file sizes. Figure 3 illustrates three *IfcAdvancedBreps* generated with MatchFEM in Grasshopper, alongside their IFC visualization in Blender (2025) using the Bonsai (2025) plug-in. The resulting IFC file has a size of 712 KB, whereas the same model generated within Bonsai produces a file size of 4081 KB, nearly six times larger. This size disparity becomes even more pronounced with larger and more complex models. These findings highlight the pressing need to upgrade existing BIM software to efficiently handle complex IFC geometries, thereby fostering the adoption of OpenBIM and enhancing interoperability.

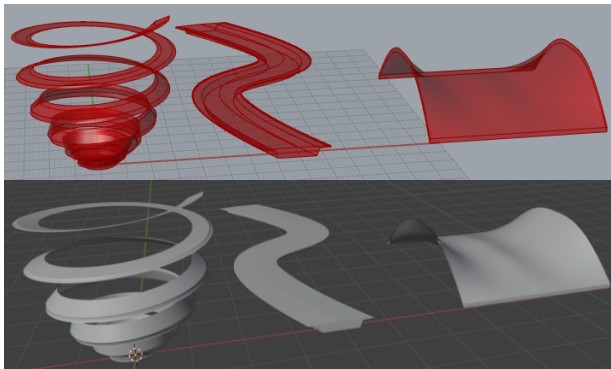


Figure 3: Grasshopper geometry and the resulting *IfcAdvancedBreps* view in Blender

In addition to generating IFC geometries, MatchFEM facilitates the incorporation of metadata to create semantically rich models that comply with the latest accepted standard, ISO 16739-1:2024 (IFC4X3_ADD2, 2024). The tool enables the creation of *IfcBuildings* and *IfcBridges*, while allowing users to define site, materials, spatial elements, and any entity within the *IfcElement* superclass. Figure 4 demonstrates the initialization of an IFC for a bridge. Users can specify details such as the project and bridge names, the type and parts of the bridge, the file name and path, as well as the editor details.

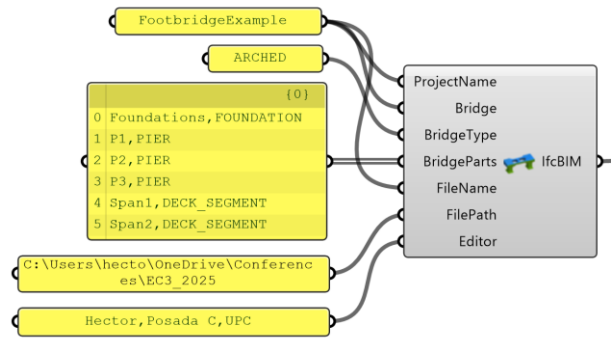


Figure 4: Initialization of an *IfcBridge* in MatchFEM

Planning and Scheduling

Adding the time component to DTs enables the monitoring of construction or maintenance tasks and supports project management simulations. Despite the availability of numerous commercial software for BIM Planning and Scheduling (4D BIM), many do not adhere to open standards, which limits collaboration and interoperability. The IFC schema facilitates planning and scheduling through its *ControlExtensionCoreLayer*. An *IfcWorkPlan* organizes *IfcWorkSchedules* for construction or monitoring activities, while *IfcWorkCalendar* defines working and non-working periods. In the *ProcessExtensionCoreLayer*, *IfcTask* enables task creation, linking to both *IfcWorkSchedule* and *IfcWorkCalendar*.

Although these entities are used in research, only a few applications support their generation and interpretation. MatchFEM allows comprehensive BIM Planning and Scheduling by implementing these entities. Figure 5 illustrates the generation of a *WorkSchedule* for bridge construction, incorporating pouring of pad footings tasks, with specific durations, start and finish times, while linking to the corresponding *IfcFootings*.

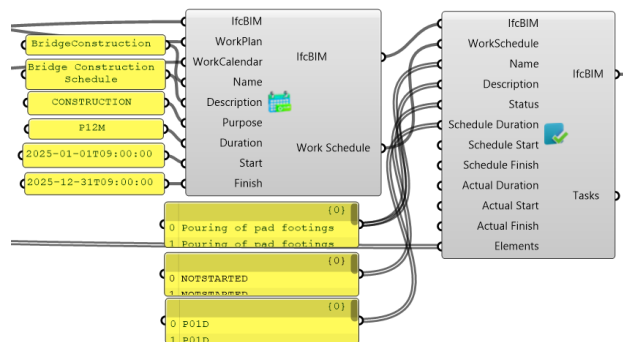


Figure 5: Generation of an *IfcWorkSchedule* and an *IfcTask* for a bridge construction

Increased availability of 4D BIM applications using the IFC schema will enhance holistic project management across an asset lifecycle, promoting information reuse and interoperability.

IoT Monitoring

One of the key features of DTs is their ability to continuously update virtual models with onsite data. IoT technology emerges as a solution for efficiently storing and managing this data. IoT refers to the interconnection of sensing and actuating devices (things) that share data over platforms using a custom cloud computing framework (Gubbi et al., 2013). Numerous commercial IoT solutions exist, each with its own architecture, and selecting the appropriate one depends on the specific requirements of the project.

In MatchFEM, one open-source IoT solution called Mainflux (2025) is connected to the plugin (other customized IoT architectures can also be added). The particular case of the Mainflux framework defines two primary entities: i) Things, representing any data source (e.g., sensors, actuators, applications), and ii) Channels, which serve as communication pathways between things. Things exchange messages via channels. The simplest setup involves creating a channel, a thing, and connecting the two, after which the thing can begin transmitting messages. MatchFEM employs user authentication to enable querying channels, managing the creation and retrieval of things, and facilitating data upload and retrieval. Additionally, it supports the coupling of *IfcSensors* with corresponding IFC elements. A BIM-IoT integration can be achieved by converting IFC Global Unique Identifiers (GUIDs) to standard GUIDs. This conversion ensures that the GUIDs of *IfcSensors* align with their associated things (see Figure 6), enabling seamless data retrieval within end-user DT platforms.

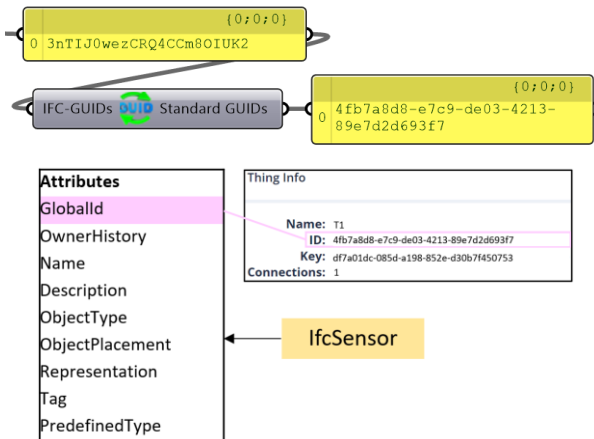


Figure 6: BIM-IoT integration by matching *IfcSensors* and things GUIDs

Figure 7 illustrates the *FromIoT* component, which enables the retrieval of thing data by providing the channel, its ID, the desired start and end times, and the user access token.

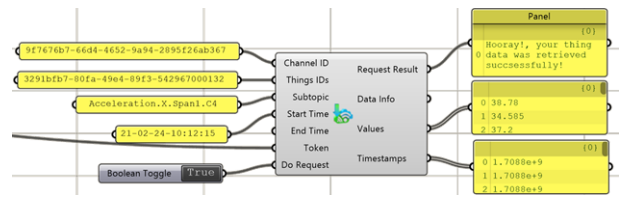


Figure 7: Retrieving of thing data in MatchFEM

The set of C# functions created to interact with Mainflux cloud framework is publicly available in the following GitHub link: [LabModelsDigitalsUPC/MainfluxIoT](https://github.com/LabModelsDigitalsUPC/MainfluxIoT).

Data Processing

Onsite data is often raw and not directly readable. Processing is essential to analyze states or conditions. Sensor-based data processing techniques enable analysis, simulations, predictions, and Performance Indicators estimation within a DT. There are many data processing techniques for diverse and multiple purposes.

MatchFEM includes a set of custom data processing components designed to estimate key physical values for assessing the performance of built assets. Currently, the platform processes accelerometer data to estimate vibration modes, strain gauge signals to evaluate deformations, Linear Variable Differential Transformer (LVDT) data to assess deflections, and concrete temperature data to apply the Maturity Method (ASTM, 2019), enabling the prediction of early-age concrete compressive strength. This set of components is expected to expand, addressing a broader range of data processing needs for construction and maintenance activities.

Figure 8 illustrates how the *Deflections* component processes LVDT sensor data to estimate span center displacements of a bridge and compare them to predictions from structural simulations. Results are output in machine-readable JSON format, facilitating seamless integration with end-user DT platforms.

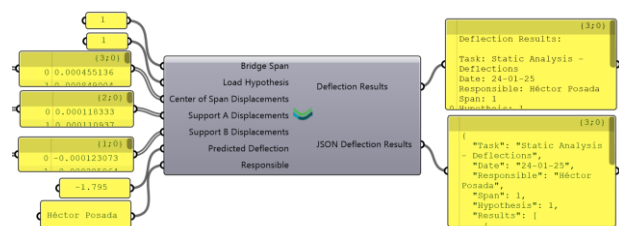


Figure 8: LVDTs data processing to assess a bridge span deflection using MatchFEM

Structural Analysis

Structural Analysis models simulate the physical behavior of built assets, providing accurate insights into the performance of structures. During construction and operation, these simulations are often performed using onsite measurements, creating a link between the physical and virtual worlds, a key capability of DTs.

MatchFEM enables the generation of structural simulations directly from Grasshopper geometry,

adhering to the IFC Structural Analysis Domain. Leveraging this open standard enhances interoperability with established commercial software, such as SAP2000 (2025) and ETABS (2025), and with web-based platforms. Figure 9 illustrates the generation of shell finite elements using MatchFEM, along with the resulting IFC Structural Analysis model in Grasshopper and its successful import into SAP2000.

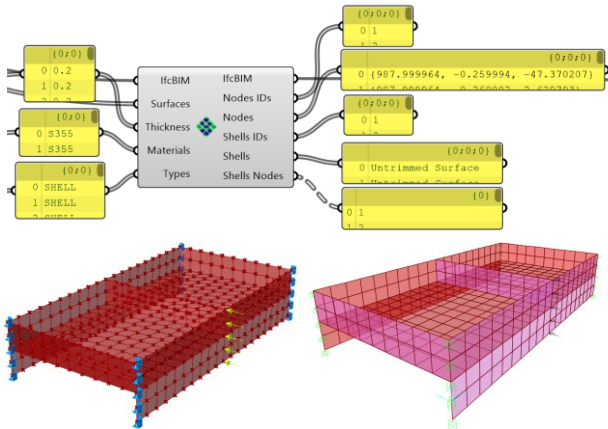


Figure 9: MatchFEM shells generation and the resulting IFC Structural Analysis model in Grasshopper and imported into SAP2000

Leveraging the powerful geometric engine of Grasshopper enables a simultaneous generation of BIM and structural models based on the same geometry, enhancing accuracy and streamlining workflows, resulting in significant time savings.

It is important to emphasize that this process is not intended to be straightforward. Effectively leveraging the geometric capabilities of Grasshopper to generate finite elements that accurately represent the structural behavior of the asset requires the knowledge and expertise of a structural engineer. This includes establishing the axes, centroids, nodes, and connections necessary to develop an accurate and error-free model.

Enabling 4D BIM generation, IoT monitoring setup, data processing, and the development of Structural Analysis models creates a robust informational foundation for operating DTs. MatchFEM also includes additional features, such as reading data from microcontrollers via the serial port and automating Uniclass (2025) classification. The plug-in is continually evolving to assist and simplify data generation for DTs.

A comprehensive description of all MatchFEM components, their functionalities, application examples, and the download link is available in the following digital book: <https://matchfem.gitbook.io/matchfem>.

Case Study

This section presents a detailed case study that outlines, step by step, the implementation workflow of MatchFEM to assist the twining of a footbridge construction. The footbridge features two spans with doubly-curved slabs

forming its deck elements. The hypothetical scenario is outlined as follows: During the design stage, the structural designer provided project information in the form of 2D drawings. The contracting firm aims to monitor the construction of the footbridge using a DT, with a particular focus on tracking project progression and concrete compressive strength.

Geometry and Metadata

As a first step, the BIM model must be generated from the provided 2D drawings. To achieve this, the 3D geometry of the bridge is created using Grasshopper CD capabilities. Once the geometry is prepared, MatchFEM is employed to convert it into IFC geometry and enrich it with semantic data. Figure 10 shows how the doubly-curved slabs are generated, setting the names, material, the spatial elements where are located (*IfcBridgePart.DECK_SEGMENT*), the geometrical representation as *IfcAdvancedBreps*, and the *PredefinedType*.

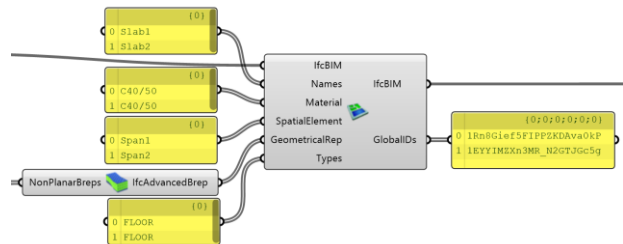


Figure 10: Generation of the slabs of the footbridge using MatchFEM

The resulting IFC and its general structure are displayed in Figure 11.

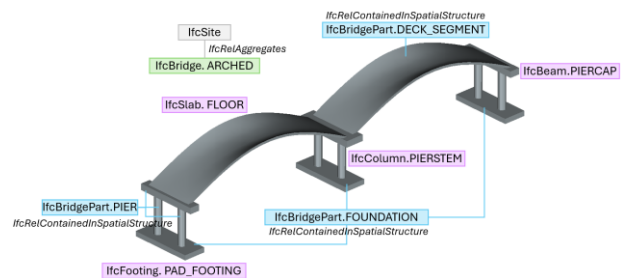


Figure 11: IFC general structure of the footbridge created with MatchFEM

Planning and Scheduling

To monitor construction progress, an *IfcTask* is assigned to each element of the bridge within an *IfcWorkSchedule*, as illustrated in Figure 5. Each task can be associated with an *IfcTaskTime*, which allows the input of both scheduled start and end times, as well as actual start and end times. This set of information within an open 4D BIM standard facilitates web-based tracking and simulation of construction progress by updating these attributes directly onsite.

IoT Monitoring

The monitoring of concrete compressive strength can be achieved by recording concrete temperatures and estimating strength using the Maturity Method (ASTM, 2019). To streamline the execution of this process, MatchFEM can be utilized to locate the required sensors, including their names, descriptions, types, parent elements to which they are connected, and display scales within the BIM. Figure 12 illustrates the creation of *IfcSensors* to measure slabs temperature, the resulting IFC file and the metadata for the *Temp 1* sensor.

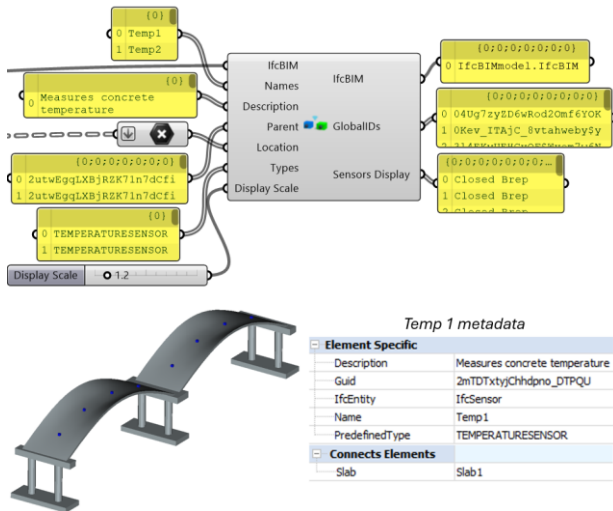


Figure 12: Creation of sensors to measure slabs concrete temperature and the resulting IFC

To integrate the created *IfcSensors* into the Mainflux IoT platform, their IFC GUIDs can be converted into standard GUIDs, enabling the creation of corresponding *things* to facilitate the retrieval and processing of concrete temperature data (see Figure 6).

Data processing

Applying the Maturity Method requires conducting a control campaign to determine the equation parameters for a specific concrete mix, enabling the prediction of compressive strength using onsite temperature data. This involves recording the temperature of two control cylinders in the laboratory and crushing three cylinders at 1, 3, 7, 14, and 28 days. MatchFEM facilitates the input of these data, along with in situ temperature measurements, to predict compressive strength at early ages. Figure 13 illustrates this process.

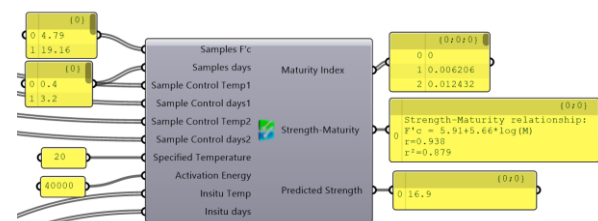


Figure 13: The Maturity Method applied with MatchFEM to estimate compressive strength with onsite temperatures

In situ temperature data can be retrieved within the same environment using the *FromIoT* MatchFEM component, as illustrated in Figure 7. This data is processed with the *ConcreteMaturity* component (Figure 13) to enable real-time predictions of compressive strength, supporting key decisions such as formwork removal and quality assurance of the concrete.

Structural Analysis

During the construction stage, structural simulations are frequently required to assess structural performance. For example, to evaluate the deflections of the footbridge slabs based on the current compressive strength estimated using the Maturity Method.

MatchFEM facilitates the generation of the footbridge IFC Structural Analysis model, leveraging the same geometry used in the BIM. By utilizing the Grasshopper CD, a smooth mesh can be efficiently generated. Figure 14 illustrates the generated model for the slabs and the process of adding boundary conditions to specific nodes.

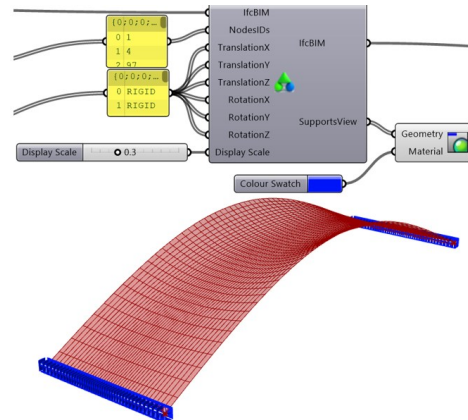


Figure 14: Footbridge slabs IFC Structural Analysis model generated with MatchFEM

The resulting model can be imported into commercial software such as SAP2000 (see Figure 9), enabling engineers to assess deflections by estimating the elastic Young's modulus based on the current compressive strength determined using the Maturity Method. This process provides valuable feedback to construction managers, supporting informed decision-making during the construction phase.

At this stage, the case study features an information construct that embodies key capabilities and attributes of DTs. It integrates a semantic-rich BIM, planning and scheduling for assessing project progression, IoT monitoring to bridge the physical and virtual worlds in real-time, and the ability to perform predictive simulations using onsite data. All these data layers were created and managed within the same intuitive visual programming environment, without requiring a single line of code. Moreover, the use of open formats and software for data generation enhances its integration into end-user DT platforms and the addition of other layers of information.

Conclusions

This paper has introduced MatchFEM, a Computational Design (CD) assistant tool designed to simplify the data generation of Digital Twins (DTs) for buildings and infrastructure. By leveraging the Grasshopper intuitive visual programming environment and its powerful geometrical engine, MatchFEM enables the seamless generation of key DT components, including 4D BIM based on the IFC schema, IoT monitoring configurations, data processing, and Structural Analysis models.

The case study demonstrated the tool's ability to integrate essential data layers such as semantic-rich BIM incorporating complex geometries such as AdvancedBreps, scheduling for project progression assessment, IoT monitoring to bridge the physical and virtual realms and enable real-time connectivity, and predictive structural simulations based on onsite data, all without requiring programming expertise. MatchFEM not only reduces complexity for AECO professionals but also facilitates interoperability through the use of open formats, ensuring ease of integration into end-user DT platforms and adaptability for future expansions.

By addressing the challenges associated with DT implementation in the AECO sector, MatchFEM represents a significant step toward enhancing efficiency, fostering innovation, and supporting informed decision-making throughout the lifecycle of built assets. Future work could explore expanding the tool's capabilities, incorporating additional layers of information, and evaluating its scalability across diverse project types and complexities.

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