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Area of 5D BIM - Virtual Design and Construction

MASTER'S THESIS

to obtain the degree of

Master of Engineering (M.Eng.)

Implementation of RFID and Wireless IoT Technologies in Building Information Modelling (BIM)

Implementación de tecnologías RFID e IoT inalámbricas en el Modelado de información de construcción (BIM)

Implementierung von RFID- und drahtlosen IoT-Technologien in digitalen Bauwerks-Informations-Modellen (BIM)

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I dedicate this work to my father, Odiljon Juraboev (Civil Engineer)

(1956-2012)

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STATUTORY DECLARATION

I am Abduaziz Juraboev, born on 18.08.1991 in Spitamen, Tajikistan; with this certify that I have prepared this thesis independently and without the help of third parties using only the sources and aids indicated. This thesis has not been submitted to any other examination authority in the same or similar form and has not been published. All passages taken from the sources are marked as such. [1]

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Note on gender-neutral language: In this Master's Thesis, the masculine form of language is used for personal Names and pronouns for reasons of simplified readability. However, this does not mean discrimination towards the female gender, but a simplification to be understood as gender neutral.

[1] The text of the declaration has been derived from a declaration template of the University of Applied Sciences THM; Retrieved at 12.10.2021; 09:09: Downloads & Links (Dipl.Inf.) (thm.de)

ABSTRACT

The integration and installation of innovative Radio Frequency Identification (RFID) technologies in combination with wireless Internet of Things (IoT) technologies in Building Information Modelling (BIM), assigned building elements, can create connectivity between the physical- and the virtual world.

Beyond the identification of physical objects, further information can be connected, which can be made available to different user groups during the entire life cycle of the building structure. This provides a high level of transparency, in that by scanning the tagged building elements, complete associated information can be accessed and presented to users via applications, in visual and audio form. One use of an RFID and BIM-supported electronic guidance system, namely for the visually impaired, has already been investigated in my bachelor thesis at the University of Applied Sciences (Technische Hochschule Mittelhessen, THM).

This Master's Thesis focuses on the implementation of passive RFID technology into BIM models in combining them with open-source software applications. BIM represents the digital twin of building models in the digital world and can be linked to physical structures (buildings, roads, sewer systems and such others) and building materials (e.g. textiles, mineral and plastic floor coverings, concrete components) by integrating RFID tags.

Connecting the parametric BIM models with the physical building elements by using RFID and wireless IoT technologies in a multi-platform application enables the BIM building models to be actively used throughout the life cycle of a building, not only by the facility management, but also by the public for various use cases.

During the literature review, suitable software and hardware components were selected, and a prototype multi-platform application for a navigation and positioning system was developed as proof of concept for the Industry Foundation Classes (IFC) file. (See Demo Version at https://opennavibim.herokuapp.com/).

The challenge was to read the RFID tags in different installation scenarios. Depending on the installation situations (under, over or in the material), various requirements were specified for RFID tags and readers (RFID, handhold personal digital assistant "PDA"). In this field, further hardware developments are necessary.

Keywords: *Building Information Modelling (BIM), facility management, a digital guidance system for the blind people, infrastructure, model-based positioning and navigation system, real-time data, Ultra high frequency (UHF), near field frequency (NFC) radio frequency identification (RFID),* Bluetooth Low Energy (BLE), *Internet of Things (IoT), Digital Twin, framework, application*

RESUMEN

Mediante la integración e instalación de la innovadora tecnología de identificación por radiofrecuencia (RFID, *Radio Frequency Identification*) en el modelado digital de información de construcción (BIM, *Building Information Modelling*), con la interconexión inalámbrica del internet de las cosas (IoT, *Internet of Things*), es posible crear una conectividad entre el mundo físico y el virtual.

Más allá de la mera identificación de objetos existentes, esta conectividad permite incorporar información adicional, que puede ponerse en disposición de los diferentes grupos de usuarios que intervienen durante el ciclo completo de vida de la estructura de la edificación. Se consigue un alto de nivel de transparencia en ese traspaso de información, accesible por medio del escaneado de los elementos etiquetados en la edificación, al tener una completa información asociada que es presentada a los usuarios vía aplicaciones en formato visual o de audio. Una investigación en la aplicación de tecnología RFID basada en BIM para un sistema de navegación electrónica, destinada a personas con discapacidad visual, ha sido desarrollada en mi trabajo fin de grado en la Universidad de Ciencias Aplicadas de Mittelhessen (THM).

El presente Trabajo Fin de Master se centra en la implementación de tecnología RFID pasiva en modelos BIM combinados con aplicaciones de software libre. El modelo BIM representa el gemelo digital de los elementos de construcción en el mundo virtual, permitiendo establecer una relación del modelo con estructuras físicas (edificios, carreteras o sistemas de alcantarillado, entre otros) y materiales de construcción (por ejemplo, textiles, cubiertas de suelo minerales o plásticas, componentes de hormigón, …) por medio de la integración de etiquetas RFID.

La conexión de los modelos paramétricos BIM con los elementos físicos del edificio, mediante el uso de tecnologías RFID e IoT inalámbricas en una aplicación multiplataforma, permite que los modelos de construcción BIM se utilicen activamente a lo largo del ciclo de vida de un edificio, no solo por la gestión de las instalaciones, sino también por el público para diversos casos de uso.

Durante la revisión bibliográfica, se seleccionaron los componentes de software y hardware adecuados, y se desarrolló un prototipo de aplicación multiplataforma para un sistema de navegación y posicionamiento como prueba de viabilidad del concepto del modelo Industry Foundation Classes (IFC). (Véase la versión de demostración en https://opennavibim.herokuapp.com/).

La lectura de las etiquetas RFID en diferentes en diferentes situaciones de instalación presenta un desafío, dependiendo de la instalación (debajo, encima o en el material) los requisitos impuestos a las etiquetas y lectores RFID son diferentes. Por lo tanto, es necesario seguir desarrollando el hardware en este ámbito.

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LIST OF ABBREVIATIONS

App	mobile app
API	Application Programming Interface
BNB	(Bewertungssystem Nachhaltiges Bauen) Assessment System for Sustainable Building
BIM	Building Information Modelling / Building Information Model
BLE	Bluetooth Low Energy
BMVI	(Bundesministerium für Verkehr und Digitale Infrastruktur) Federal Ministry of Transport and Digital Infrastructure
BMWi	(Bundesministerium für Wirtschaft und Energie) Federal Ministry for Economic Affairs and Energy
bS	buildingSMART
BPMN	Business Process Model Notation
CAD	Computer-Aided Design
CDE	Common Data Environment
CSS	Cascading Style Sheets
DB	Database (Datenbank)
DGNB	(Deutsche Gesellschaft für Nachhaltiges Bauen) German Sustainable Building Council
FM	Facility Management
GPS	Global Positioning System
GIS	Geographic Information System (Geografisches Informationssystem)
GitHub	Provider of Internet hosting for software development and version control using Git (Global Information Tracker)
Heroku	Heroku Cloud Application Platform
HF	High Frequency
HTML	Hypertext Markup Language
ID	Identification Number
IFC	Industry Foundation Classes
IoT	Internet of Things

LIST OF ABBREVIATIONS

IT	Information Technology
ISO	International Organisation for Standardization
JS	JavaScipt
JSON	JavaScript object notation
LAN	Local Area Network
LOD	Level of Detail / Level of Geometry; Level of Development
LOI	Level of Information
LPWAN	Low Power Wide Area Network
MongoDB	cross-platform, document-oriented database program
MeteorJS	open-source JavaScript web framework written using Node.js
Node.js	open-source, cross-platform for back-end JavaScript environment
npm	Node Package Manager
NB-IoT	Narrowband Internet of Things
OGC	Open Geospatial Consortium
PDA	Personal Digital Assistant
PoC	Proof of Concept
POI	Point of Interest
Rest API	Representational state transfer Application Programming Interface
RTLS	Real Time Location System
RFID	Radio Frequently Identification
Stack Overflow	Stack Overflow is a question-and-answer website for programmers
STEP	Standard for the Exchange of Product Data
Tag(s)	Transponder(s)
UC	Use Case
UHF	Ultra High Frequency
UWB	Ultra-Wide Band
UID	Unique Identification Number
WAN	Wireless Area Network
WSN	Wireless Sensor Networks

STRUCTURE OF THE THESIS

Diagrammatic presentation of Thesis Structure with main chapters.

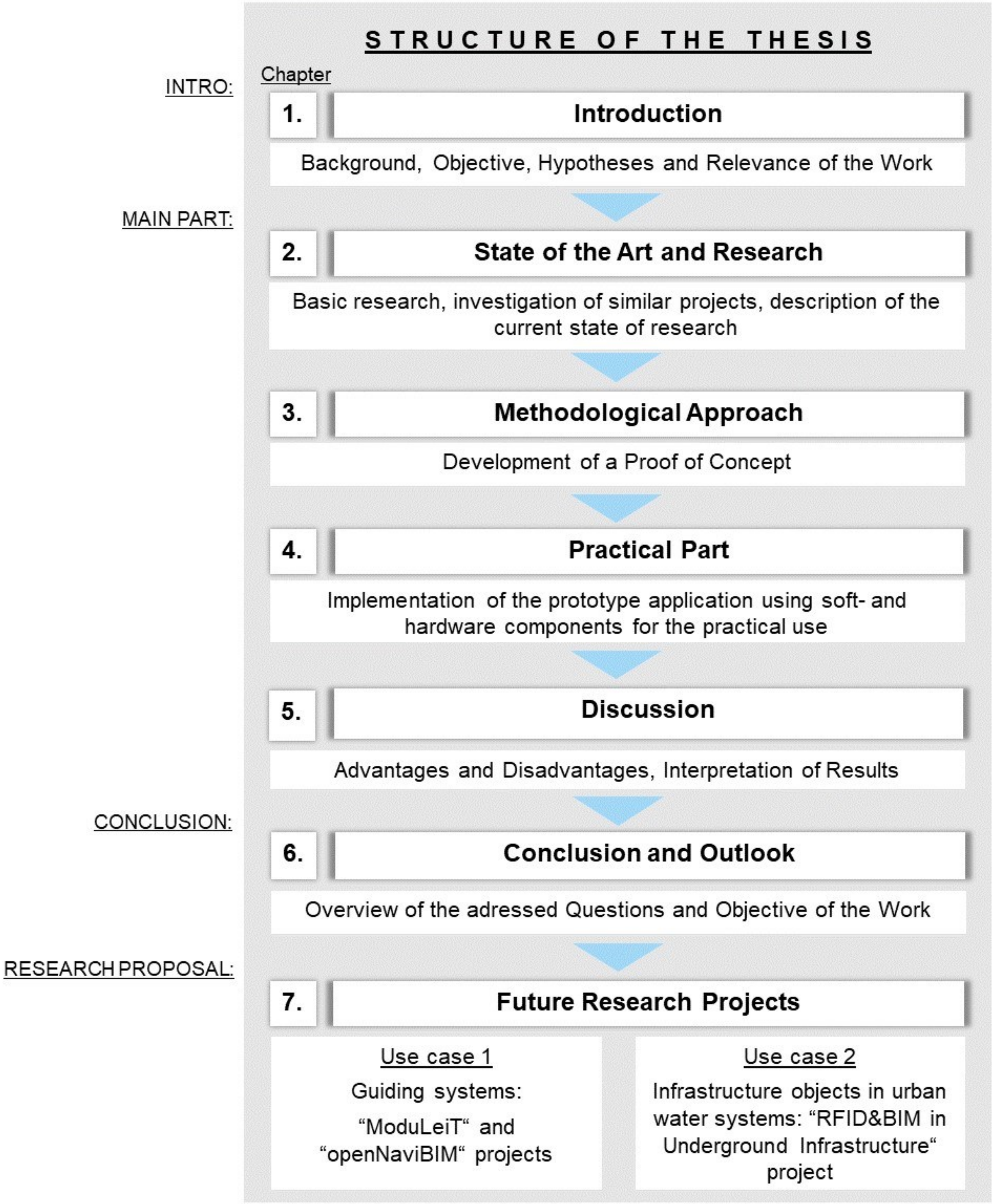


Figure 1: Structure of the Thesis

1 INTRODUCTION

1.1 Background and Problem Statement

The use of RFID, Sensors and wireless IoT technologies is becoming increasingly significant for the further development of BIM. Today products, such as RFID technologies, sensors and beacons are used in the planning and construction process of construction projects to make the processes and progress on construction sites more effective, and to assign information to the construction objects and to document it.

The research of RFID and wireless IoT technologies and their integration into BIM building models were methodically and practically investigated based on two concrete and the feasible applications using the following questions:

- What is the current state of the art and research of integrating RFID and IoT technologies in BIM projects?
- Can we use the model-based data in the operating phase of the structure over its life cycle, and would this provide additional value?
- Can digital BIM models be linked to the physical structures in real-time using RFID technology as a digital twin, for example setting up a navigation and positioning system?
- What opportunities are provided by RFID and wireless IoT technologies based on BIM systems for barrier-free mobility and physical infrastructure objects?
- Which software and hardware components can we use to implement RFID and wireless IoT technologies in BIM building models?

With regard to application possibilities the following problems were investigated:

A. Use Case 1 - Centimetre accurate pedestrian guidance system for the blind and people with limited mobility

An essential component for visually impaired people is independent mobility and information acquisition. Orientation is, almost everywhere, prerequisite for independent participation in society. In unfamiliar buildings it is particularly problematic. Tactile guidance systems are increasingly being provided outdoors, but they usually only up to the building entrance. For indoor areas, tactile aids (warnings) are available as knobs and strips made of plastic or stainless steel that can be attached to existing floor coverings. However, these guidance systems have hardly been used so far because they usually interfere with the design concept. Optical guidance systems can help a visually impaired person with orientation, while blind people can use haptic guidance systems. However, these systems do not provide any information about the surroundings, only directional and potentially dangerous information.

B. Use Case 2 - Infrastructure Objects in Urban Water Management

When digitisation began, most construction projects were designed and realised in CAD programmes. The next step was to integrate the data into geographic information systems. This allowed the objects to be registered, managed, analysed and visualised in geodatabases.

The next step was to merge the data into a NIS (Network Information Service) system in order to plan and document data regarding the facilities, from planning to the end of the operation, including the necessary maintenance work. Only a few steps are missing to complete NIS to a full twin with regard to BIM systems. Reliable recognition of the object on site is not always possible. Likewise, in the real world, for example, signage can point to the objects, but does not show them. Also, GPS data often is not accurate, for example in detecting Infrastructure objects. This requires high-resolution GPS instruments, which are also used in Geodesy. The water supplier and wastewater disposal company (MWB) in the city of Giessen uses such systems for the maintenance and servicing of road inlets (water gullies).

The focus of this Master Thesis is the investigation of software and hardware solutions for the integration of RFID and wireless IoT technologies into BIM systems based on the above mentioned use-cases. It aims to deliver a basis for the practical application through the implementation of RFID and wireless IoT technologies into BIM processes to provide preliminary work for the above defined applications based on BIM systems.

1.2 Aim of the Work

The aim was to develop a prototype application as a proof of concept for incorporating RFID and wireless IoT technologies into BIM models by using the Industry Foundation Classes (IFC STEP 21) data exchange format in the building industries for navigation, tracking, and information systems.

Based on the results of my previous studies in the methodological and practical laboratory investigations, this thesis focuses on developing software application frameworks for the integration of RFID and wireless IoT technologies into BIM systems based on the above mentioned use cases.

Solutions for this were sought in order to investigate this for the further use of structures in the operational phase with regard to the integration of RFID transponders (tags) in or under different materials (e.g. textile, mineral and plastic floor coverings, concrete components etc.).

In order to accomplish this, further investigations were carried out to implement the software and hardware solutions into the above-mentioned use cases, and a “Proof of Concept" was designed. With regard to this work, the Use Cases (guidance system for the blind and infrastructure objects with regard to inflow sources by urban water management) have similar interfaces:

- Secure and real-time communication of RFID tags placed in building materials with the help of software tools.
- Development of database and server applications to support model-based data storage and management.
- Development of an App to link the data with peripheral devices (e.g. smartphones, tablets and RFID readers).
- Real-time connection of the virtual world (data, information) with the physical world.
- Connection of the software and hardware components.

The knowledge gained will be transferred to planned and further research projects at the THM.

1.3 Hypotheses

If the passive RFID tags and wireless IoT technologies can be integrated into the building materials and objects (e.g. paving slabs, floor carpets, maintenance holes and sewer systems) during the manufacturing process, the corresponding hypotheses will be investigated and checked.

In this thesis following hypotheses are reviewed:

- RFID tags can be embedded in or under various building materials (floor coverings, concrete materials and the like), and BIM-based data can be scanned and visualised with the help of an application.
- Embedding RFID tags in building products facilitates the tracking and identification of objects in georeferenced systems.
- Digital and physical objects can be linked in real-time via an application using RFID technology, wireless IoT technologies and BIM systems.
- With the networking of digital models and physical building objects, innovative technologies can be used to develop further possibilities for model-based maintenance and navigation and location systems in connection with mobile devices.

1.4 The scientific and practical relevance of this Work

The motto of the BIM Congress (September 2021) entitled "Infrastructure digital planning and building 4.0” was: “BIM is more: Digitization in construction continues” [1], that was organised for the eighth time at THM. One of the main focuses of the congress was the further development of digitalisation in construction through the implementation of digital twins in real-time. Today, numerous companies have already succeeded in implementing BIM and Digital Twin in practice.

In the context of this Work should be investigated, whether many international research institutions have already dealt with the integration of RFID and IoT technologies into BIM systems and the complexity in practical application.

In particular, the inclusion of BIM with RFID and sensors, and the applications for the further use of the system in operation. It was argued that specifically 7D-Facility Management should be highly valuable in terms of scientific understanding and social impact.

For this reason, the software and hardware implementations were to be examined and scientific guidelines developed.

From a scientific point of view, the following three aspects have relevance for this work:

- Research on the state of the art, science and the existing systems in the market.
- Development and implementation of synergies for the solution approaches using agile methods, such as MindMaps, Design Thinking process and BPMN methodology.
- Investigation of the implementation of the above systems using practical examples.

The BIM approach is already being widely used in design and construction, but there is a research shortcoming due to the lack of Applications in the operational phase for 7D BIM facility management.

From a commercial point of view, the following three aspects are relevant to this work:

- The application-oriented and the synergy-based concept provide a guideline for the design of new innovative solutions.
- User information by providing theoretical and practical knowledge describing the inclusion of RFID and wireless IoT technologies with regard to building and construction materials.
- Demonstrate the feasibility with help of an application which integrates RFID technology in the BIM and the building materials.

In my work for this thesis, practical proof of concept was developed to implement a multi-platform application for the above-mentioned use cases using and integrating innovative technologies (RFID and wireless IoT technologies) into BIM.

2 STATE OF THE ART AND RESEARCH

2.1 Preliminary Remarks on the Literature Investigation

In this Chapter, the definitions of terms relevant to this thesis are explained in more detail, and a literature review is presented to illustrate the content of the subject. It describes and analyses research on similar projects and emerging technologies, which form a basis for the methodological and practical part of this thesis.

The scientific approach to the literature review is summarised in *Table 1*.

Table 1: An academic approach to framing the topic in terms of content

Item	Content
Topic of the work	"Implementation of RFID and wireless IoT technologies in Building Information Modeling (BIM)"
Sub-aspects of the topic	• Integrating RFID and IoT technologies into BIM systems for further operations (facility management). • Integration of RFID technology into BIM for the development of navigation and positioning systems. • Development of digital twins using RFID and IoT technologies for practical use cases.
Research questions	(see *1.1*)
Main goals	• Research and analysis of software and hardware components used in research and praxis for BIM, RFID and IoT applications. • Investigation of the subject-related and technological requirements to develop a proof of concept (POC). • Development of a Prototype Application.
Used databases and search tools	• WTI Frankfurt (Scientific and Technical Information eG) • Web of Science Core Collection • Science Direct (Elsevier, Scopus) • IEEE Xplore • Technology Collection (ProQuest) • Springer Link • Stackoverflow • Google Scholar, Google und Wikipedia
Languages and references	The parts of literature references have been translated by the Author and the sources were marked in the text passages.
Terms and keywords	Building Information Modeling (BIM), Digital building, IFC, Digital Twin, Facility Management (FM), GIS, Internet of Things (IoT), RFID, UHF, NFC, Chip, Wireless, Sensor, Beacon, Framework, Application, cloud solutions, Development environment (IDE), Navigation, guidance system, Indoor, Outdoor, Tracking, Localization, Sewer detection, Sewer systems, Guidance system for the blind.

2.2 Research on Building Information Modeling (BIM)

2.2.1 Definitions of Terms

The term "Building Information Modelling" (BIM) is interpreted widely. There are different definitions depending on the field of application.

Table 2: Set of terms used in the BIM working methodology

Term	Definition
Building Information Modeling	Building Information Modeling refers to a working methodology in which all data and information relevant to the entire building life cycle are recorded, managed and processed based on a digital, three-dimensional building model [1]. This information is exchanged transparently among the involved parties and provided for further processing. The collected data and information are used for the planning and execution as also for the operation and restoration of the structure [2]. “A Building Information Model (BIM) is a comprehensive digital image of a building. It typically contains the three-dimensional geometry of the single elements of the building in a defined level of detail. It also includes non-physical objects, such as rooms and zones, and a hierarchical project structure. These objects are typically associated with a well-defined set of semantic information, such as the component type, materials, technical properties, and the relationships between the components and other physical or logical entities.“ [3] On the one hand, BIM is a process for creating, modifying, and managing such a digital building model with the help of relevant software tools. “On the other hand, however, this term is also used to describe the use of the digital model over the entire life cycle of the structure - from planning, through execution, to management and finally to dismantling.“ [3]
Building Information Management	Building Information Management describes the processes that take place beyond the model approach. This involves the processes that define the evaluation and use of the models concerning the planning of construction workflows, quantities, and costs. Furthermore, there is a high value on the handling, documentation and further processing of the data and information.
3D-Model	The 3D model describes a three-dimensional, digital image of the real building, which contains all physical and functional properties as well as the data and information of the building relevant for the entire life cycle of the structure. The three dimensions are represented by the representation of the spatial X, Y and Z axes [4].

4D-Model	The 4D model describes the extension of the 3D model by the time component. By assigning the model elements to individual events of the schedule, it is possible to generate a construction sequence animation of the model and the temporal sequence of the construction process based on a virtual representation of the structure (4D = 3D + time). [4].
5D-Model	The 5D model extends the 4D model to include the cost component. The model-based quantities are linked with the costs and calculations stored. In this way both, a cost calculation and the cost progression during construction, can be mapped using the model (5D = 4D + costs) [4].
6D-Model	The 6D model dimension refers to the extension of the 5D model to include information on sustainability and efficiency. The concept of sustainability (6D) can be divided into: • Environmental sustainability - the ability to improve the environment, • Economic sustainability - the ability to create income and generate employment, • Social sustainability - the ability to create human well-being [5] (6D = 5D + Sustainability and Efficiency) [4].
7D-Model	The 7D model dimension describes all informations that are necessary for the operation of the building, such as maintenance/operating instructions, warranty data, manufacturer information and contacts. This enables building operators to have BIM-based maintenance and repair management *(7D = 6D + Facility Management)* [4].
Attribution and modeling requirements	The attribution guidelines define the data and information that must be stored on the components in the form of attributes. The type and scope of the attribution depend on the respective use of the model in the project. They must be formulated on a project-specific basis. The modelling specifications describe the requirements needed for the models. They define the specifications that must be adhered to when creating the models and how these are implemented.
Attributes and parameters	An attribute is a geometry specification or an alphanumeric property of a model element (e.g. material specifications, structural properties), consisting of an attribute name and the associated designation. “An attribute describes only a single detail of a property or a group of properties.“ [3] The terms property, property group and others are defined in more detail in DIN EN ISO 23386:2020 [6]. Parameters are evaluable object properties of the object models (e.g. in the form of variable wall heights that influence the geometry of single model elements).

Common Data Environment	CDE (Common Data Environment) is a central platform (repository) where all project information is housed, exchanged and archived. The CDE is also used for communication between all project participants. Each project participant receives appropriate access to the platform through adapted roles and rights. The digital collaboration platform (CDE) is the only source of information in a BIM project [7].

2.2.2 Why BIM?

“BIM focuses on an intelligent building data model that contains not only the 3D dimensions, but also all relevant data about the building.“ [8]. The implementation of BIM-based processes at the early stage in the planning phase results in improved planning quality, reduced effort in later phases (construction and maintenance) [3] and has many other advantages such as:

- Technical drawings (floor plans, sections, views, etc.) can be generated directly from the BIM model for further use without any interference between them.
- For the early identification of problems, collision checks can be carried out between the technical models of the different groups.
- Application of a digital construction model for tenders, calculation, scheduling and cost information, deficiency management, etc.
- A digital building model can be updated at any time with information that can be used, for example, in facility management.
- All changes to the physical structure can also be updated in the digital image (BIM model). This ensures that the model remains accurate and congruent with the building.
- The digital building model can be made available for further applications.

2.2.3 Implementation of the BIM Methodology

Implementation of the BIM methodology is differentiated according to the terms "BIG BIM", "little BIM", "Open BIM", and "Closed BIM", based on the application case:

- **"little bim":** The use of specific BIM software by a single planner to solve a particular task.
- **"BIG BIM":** Consistent model-based communication between all stakeholders across all phases of the life cycle of a structure (building).
- **"Closed BIM":** Use of software products from a single manufacturer and use of proprietary data exchange formats.
- **"Open BIM":** Use of software products from different manufacturers and use of open, non-proprietary data exchange formats.

The combination of these approaches are illustrated in *Figure 2* in the form of a matrix by Bohrmann [3].

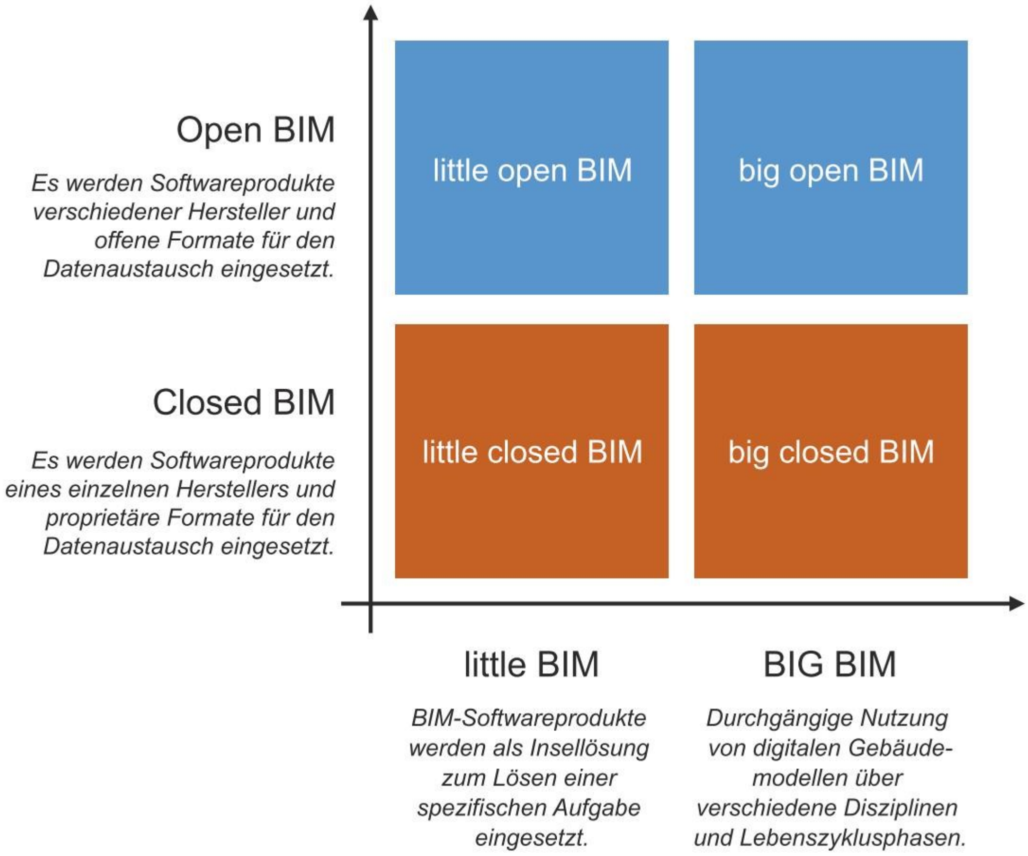


Figure 2: Matrix to differentiate little bim vs. BIG BIM, Closed BIM vs. Open BIM [3]

The purpose of providing digital building models in *"big open BIM"* is the interaction of non-proprietary formats in the future. According to Bormann, there are still limitations in the transfer of models between different modelling tools for further processing. The reason is that creating non-proprietary or standardised formats and correct implementation by the software companies are technically quite challenging [3].

The Open BIM approach has many advantages for collaboration in the planning, execution, operation phases, as the involved parties can use different software applications.

2.2.4 Standards and Norms

The basis for the *openBIM* data exchange is the “IFC Standard”, an open, non-proprietary, international standard in its ISO 16739-1:2018 version especially for BIM. With the help of the IFC format, BIM data can be exchanged and shared between different software applications [9]. Furthermore, IFC is a general data schema that includes all information of all life cycle phases involved in a construction project. BuildingSMART International developed the IFC format [8].

Nowadays (2022) the following IFC file versions [8] are in use:

- **IFC4:** Not all software tools fully support IFC4.
- **IFC2x3:** Presently the most supported and most stable format.

It is essential to ensure compatibility with IFC when selecting software. “One of the essential concepts for IFC data exchange is the model view definitions (MVD). Model view definitions are data filters that precisely define the graphical and alphanumeric information that must be included in the data exchange. An MVD is, a part of the entire IFC schema.“ [8].

2.2.5 Level of Development of BIM-Models

Levels of development are used for the exchange of data or information. These are related to digital deliverables[2] (e.g. files) in the form of BIM models [11].

Table 3: Levels of Development and Detail

Term	Definition
LOI	Alphanumeric Information Quality of an object. "Level of Information" is defined in the Norms and indicates how detailed the characteristics of a component (wall, ceiling, column) or an object (chair, table, lamp) must be in the respective performance or project phase [12].
LOG	Geometric level of detail of an object. "Level of Geometry" describes the geometric accuracy of the models that must be created [12].
LOD	"Level of Development" describes the degree of completion at the respective time of the project. LOD results from the level of detail and information of the components and objects of a model (LOI + LOG). LOD is usually combined with a specific design phase [13].
LOIN	“Level of Information Need describes requirements for the model in terms of alphanumeric information, geometric information and further documentation.“ [3].

2.2.6 Status Quo BIM

In Germany, from the end of 2022, the BIM method will be implemented in all new federal buildings to be planned, according to the "Masterplan BIM Bundesfernstraßen" initiated by the Federal Ministry for Digital and Transport (BMDV), and developed by the group of experts [14]. At the same time, companies and research groups are working on automatically creating BIM models for existing buildings and, if necessary, with artificial intelligence [15].

In Spain, there is a national implementation strategy for BIM, namely the Pública. Liderada por el Ministerio de Transportes, Movilidad y Agenda Urbana. According to Comisión Interministerial BIM (*cbim)*[3]; however, BIM is not mandatory in Spain [16]. The objective is: All public facilities and infrastructures (all new construction and refurbishment projects) are to be created with BIM in all phases (planning, construction, maintenance) [17]. Further implementations of innovative technologies such as sensors, RFID, IoT, etc., are required to connect the physical structures (objects) and the digital representation in the next stage. The goal is the development of a digital twin.

[2] „Digital deliverables are all files that have to be handed over to the client as a result of a service at the end of a certain service phase.“ [10].
[3] Comisión Interministerial BIM

2.3 Research on RFID and Wireless IoT Technologies

2.3.1 Definitions and Terms

RFID (Radio Frequency Identification) describes a technology for transmitter-receiver systems that enables automatic and wireless identification and localisation of objects using radio waves [18].

The term "Internet of Things" (IoT) was first used in the late 1990s by researchers at the Massachusetts Institute for Technology (MIT). The basis for the development of IoT technologies is Radio Frequently Identification (RFID), as an intelligent localisation and identification technology (machine-to-machine communication) of objects, using radio waves [19], [20]. While RFID technology can uniquely identify objects, IoT technology offers the possibility to exchange data with other devices and systems via the internet or other communication networks with the help of software and hardware.

2.3.2 Why RFID?

So far RFID technologies have been researched in the construction industry in connection with BIM work methodology for automated construction progress recognition, occupational health and safety, orientation and way-finding in case of fire, construction monitoring, as well as tunnel construction, and they are currently being technically developed for the digital transfer from what to a digital processes [3]. For example, ARGE RFIDimBau[4] within the ZukunftBau research initiative, has been working on several research projects on the concerning of digital building models and RFID technology in the construction and real estate industry since 2006. Within the framework of the research project "BIM-based construction with RFID", “[...], a standardisation concept has been developed for connecting the reference data that result from planning with the actual data that are recorded over the life cycle of a building using RFID technology. Furthermore, the focus of the research project is the public relations work to establish the ideas for the use of RFID technology in the digitisation of the value chains of the construction industry.” [21].

“Auto-ID technology's essential function and mission are to provide information about objects (people, animals, goods or merchandise). RFID systems expand traditional Auto-ID methods' functionalities and application possibilities and offer a high potential for increasing efficiency […]“ [22]. The use of RFID systems is offered in a large number of variations. The bandwidth of RFID solutions is extensive. According to a study by the German Federal Office for Information Security, an RFID system is defined by the following three characteristics:

[4] ARGE RFID-Technology in the construction industry is a joint project of the Technical University of Dresden, the University of Wuppertal and the Technical University of Darmstadt.

1. **“Electronic Identification:** The system enables objects to be uniquely identified by electronically stored data.
2. **Wireless data transmission:** The data can be read out wirelessly via a radio frequency channels for identification of the object.
3. **Send on call:** A marked object only sends its data when a particular reader calls up this operation.“ [22]

2.3.3 Structure and Functionality of an RFID System

Today's RFID systems are built on three elementary inventory layers:

- Reader = Antenna (RFID-Reader),
- Information Unit = Transponder (RFID),
- Middleware = Assessment Unit (server) [23].

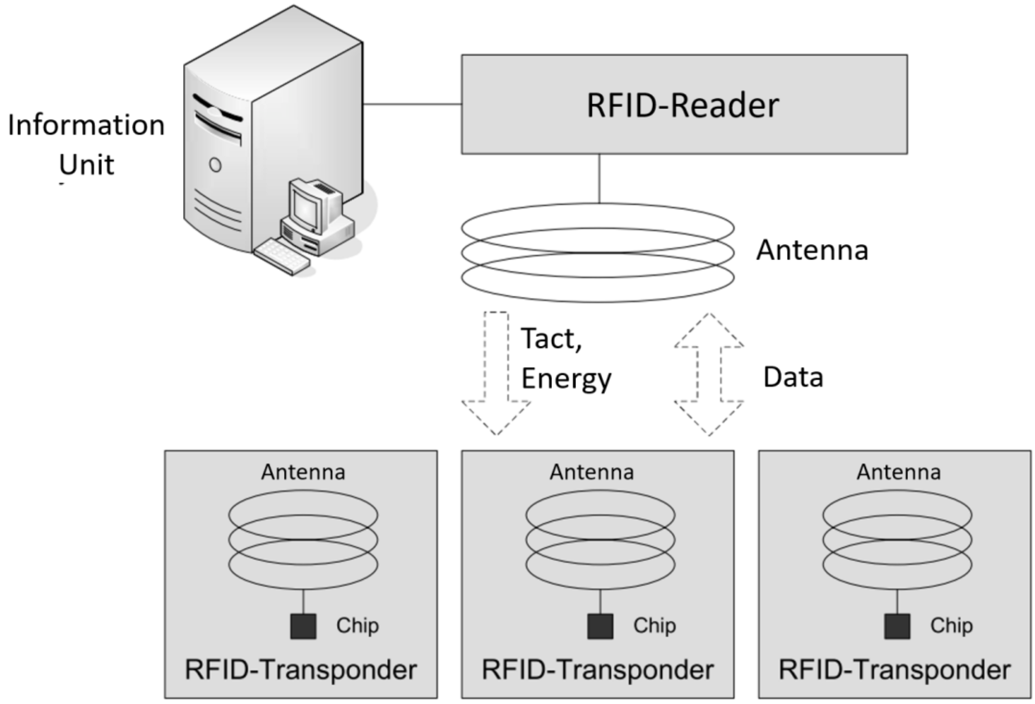


Figure 3: Components of an RFID system [24]

The following components are required for reading out the assembly:

“**The transponder** – also known as a "tag" - functions as the actual data carrier. It is attached to an object (e.g., goods or packaging) or integrated into an entity (e.g. a chip card) and can be read contactless via radio technology and, depending on the technology, also written-to again. The transponder consists of an integrated circuit and a radio frequency module. An identification number and further data about the transponder itself or the object to which it is connected are stored on the transponder.

The reader – typically described as: consists of reading or read/write unit and an antenna, depending on the technology used. The reader reads data from the transponder and, if necessary, instructs the transponder to store further data. Furthermore, the reader controls the quality of the data transmission. The readers are typically equipped with an additional interface to forward the received data to another system (PC, vending machine control) for further processing." [22].

Differences between active and passive transponders

One of the essential differences between RFID systems is the energy supply. A key differentiation is made between passive and active transponders.

Active or semi-passive transponders contain a battery that provides all or some energy to operate the microchip ("back-up battery"). This increases the communication range. The energy supply is used to manage the RFID and for data transmission.

Passive transponder systems do not have a power supply of their own. All the energy required for operation is taken in the form of a magnetic or electromagnetic field, the antenna, and transmitted to the antenna of the passive transponder [24].

Table 4: Characteristics of passive RFID transponders (modified)

Parameter	LF (Low frequency)	HF (High frequency)	UHF (Ultra high frequency)
Frequency range	125 -134 kHz	13,56 MHz	862-928 MHz
Read range (range, in air)	Up to 1,2 meter	Up to 1,2 meter	Up to 4 meter
Reading speed (depending on ISO standard)	Low	High	Very high
Transponder size	Small / Medium	Medium	Medium / Large
Obstruction through metal	Negative influence	Negative influence	Negative influence
Alignment of the tag during scanning	Not necessary	Not necessary	Partly necessary
Today's ISO standards	11784/85 and 14223	14443, 15693 and 18000	18000
Typical transponder types	Glass tube transponder, transponder in plastic cover, smart label smart cards, chip cards	Smart Label, Industrial transponder	Smart Label, Industrial transponder

Characteristics of passive RFID transponders are different (see *Table 4*) [22]. The reading distance (range) of passive RFID tags depends on the power output of the RFID reader (transmitter/antenna). Experience shows that the higher the transmitting power of the RFID reader, the more extensive the range of the RFID tag.

One factor that influences the receiving range is the coverage of the RFID tag. The shielding depends on the installation situation (a. on the surface, b. in the building material and c. under the building material). The range of the RFID tag is small for denser covering material (see *Figure 4*).

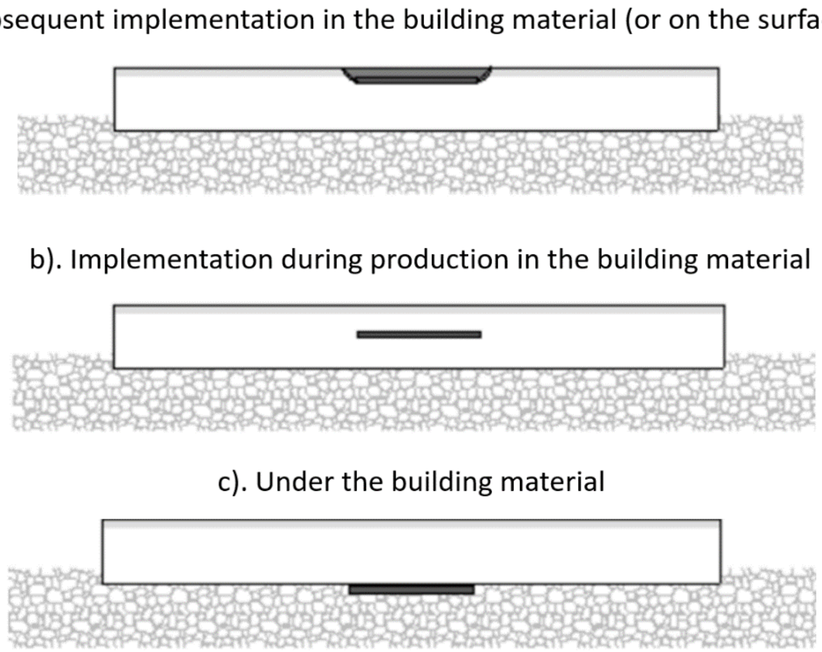


Figure 4: Types of RFID transponder insertion in building materials (modified) [25]

2.3.4 Real-Time Locating Systems and Identification Technologies

“Real-time locating systems (RTLS) are used to automatically determine and track the location of objects or people in real time. RTLS can be used, for example, to trace pallets in warehouses, to locate medical equipment in a clinic, or to track people for security purposes. In a server-based localization system, signals from transmitter hardware or mobile devices are received by stationary receiver hardware. The data is then sent to a server and the position is calculated. The most common positioning technologies include Wi-Fi, Bluetooth Low Energy (BLE), Ultra-wideband (UWB) and RFID.“ [26].

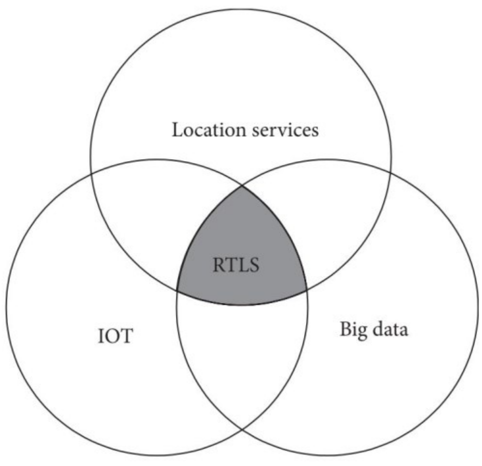


Figure 5: RFID-based real-time tracking system [27]

Until today, there is no indoor positioning system that can be compared to existing Global Navigation Satellite Systems (GNSS), such as GPS or GLONASS, in terms of usage, availability and accuracy. Proposed solutions rely on technologies such as WLAN, RFID, Bluetooth Low Energy (BLE) or Ultra-Wide-Band (UWB) combined with various metrics and algorithms to enable indoor location [28].

2.3.5 Pros and Cons of RTLS Technologies

The difference between RTLS and RFID is that the RTLS system uses a combination of Bluetooth, Wi-Fi, ultrasound, UWB, ZigBee technologies and GPS to monitor and track objects and interactions as they occur. One problem with using RFID is that radio signals cannot pass through floors, walls or ceilings in the long-range. However, both systems can be combined with application development, which is costly [29].

Table 5: Pros and cons of and qualitative comparison of RTLS-based communication and positioning technologies

RTLS	Pros	Cons
RFID-Tags	RFID uses radio waves to identify objects. Passive RFID technology only works in the vicinity of unique RFID readers that generate an energy field and activate the RFID tags. The exchange of information can only occur when the reader and RFID tag are nearby. The technology only allows localisation at a specific point (where the reader is located) [26], [30], [31] Accuracy: < 30 cm	
	• low cost per tag • no battery required • locate maintenance and servicing equipment easily • high locating accuracy • suitable for point location	• short range • Installation requires extensive planning • Infrastructure can be expensive • suitable only for point detection • RFID reader must be matched to the respective RFID tags. • Transmitting power depends on the installation setting.
Wi-Fi	Wi-Fi based positioning systems determine the location of devices with activated Wi-Fi (e.g. smartphones, tablets) and Wi-Fi tags. The accuracy of Wi-Fi for server-based indoor positioning varies from eight to 15 meters. The achievable positioning accuracy depends on conditions such as reflection in corridors and the shielding of signals from walls or the user's own body [26] Accuracy: < 15 m	
	• all Wi-Fi enabled devices can be tracked, even without logging into the Wi-Fi network • suitable for area detection	• relatively inaccurate (8-15m) • high energy consumption of Wi-Fi tags • unsuitable for point location

<table>
<tr><td rowspan="2">BLE Beacons</td><td colspan="2">• Beacons are small wireless radio transmitters that use Bluetooth Low Energy to transmit data. They are relatively inexpensive, can operate for up to five years or more on a button cell battery, and have a range of up to 70 meters indoors [26].
Accuracy: < 7 m (for BLE Bluetooth 4.0)</td></tr>
<tr><td>• hardware is cost-effective and unobtrusive
• low energy consumption
• accuracy is sufficient for most applications
• suitable for area detection</td><td>• attenuations in the signal dispersion within buildings
• Infrastructure can be expensive
• unsuitable for point location
• regular replacement of the battery necessary</td></tr>
<tr><td rowspan="2">GPS</td><td colspan="2">GPS (Global Positioning System) is a satellite-based navigation system used to determine location and time. The location determination includes the geographical longitude and latitude and the altitude. The accuracy of GPS position determination varies greatly and depends on the method and the external conditions for the GPS receiver used [32].
Accuracy: 3-10 m</td></tr>
<tr><td>• suitable for point location
• available on any mobile device (smartphone, tablet)</td><td>• low locating accuracy
• Location inside buildings not possible</td></tr>
<tr><td rowspan="2">UWB</td><td colspan="2">“Ultra-wideband is a short-range radio technology. The positioning accuracy is less than 30 centimeters, which is significantly higher than what can be achieved using beacons or Wi-Fi. Differences in altitude can also be determined very accurately. Furthermore, very low latency times can be realized.” [26]
Accuracy: < 30 cm</td></tr>
<tr><td>• high accuracy
• accurate measurement of height differences low latency times
• almost interference-free with constant line of sight</td><td>• cost-intensive
• shorter battery lifetime than BLE beacons</td></tr>
</table>

2.3.6 Basics and Characteristics of IoT Technologies

When using the term IoT, a technical vision, in which various objects are connected and integrated and interact digitally with each other, is talked about. This require the appropriate communication technologies, common standards and interfaces which enable a connection between the physical objects and the virtual world.

Basic requirements of an IoT network result from the following three properties (sensors, connectivity and people and processes):

1. **Sensor or devices:** Detect data from the environment with the help of sensors or devices. A device can have for example several sensors.
2. **Connectivity:** Required communication between the potential technologies Wide-Area Network (WAN), Local-Area Network (LAN), Cellular and Low-Power Wide-Area Network (LPWAN) for networking assets in the cloud.
3. **People & Processes:** Analysis of the collected data in the IoT systems (e.g. cloud) for further implementation of the business models. Acceptance- and user-friendly, intelligent representation of the technology for the competitive market [33].

Figure 6: Presentation of the basic requirements & characteristics of an IoT network [33]

The challenging features of the IoT in the construction sector include appropriate and scalable (primarily wireless) sensor networks and devices with robust and secure architectures, open data formats and interfaces, and their interrelationships in the harsh and dynamic working environment. In the IoT a relatively large number of spontaneous events need to be managed, knowledge created and shared from large amounts of data, while protecting people's privacy [34].

2.3.7 Pros and Cons of IoT Technologies

The different approaches to connectivity distinguishes between wired and wireless solutions. The advantages and disadvantages of the potential technologies WAN, LAN, Cellular and LPWAN are shown in *Figure 7*.

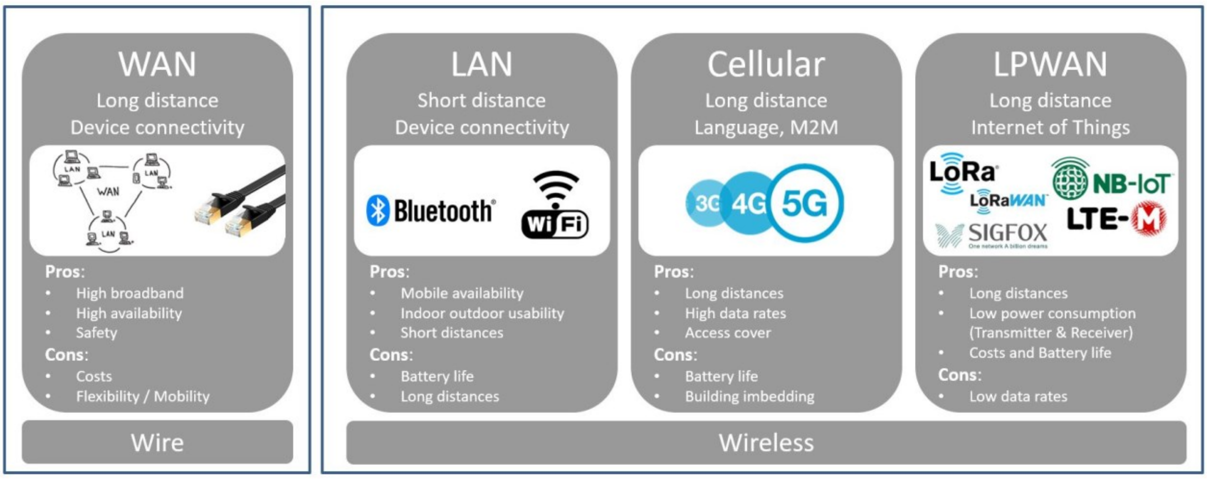


Figure 7: Advantages and disadvantages of the different connectivity approaches (modified) [33]

The Internet of Things (IoT) is a promising technology. It is revolutionising how buildings and facilities can be connected via heterogeneous smart devices through wireless connectivity to improve the quality of people's lives [35],[36], [37], [38].

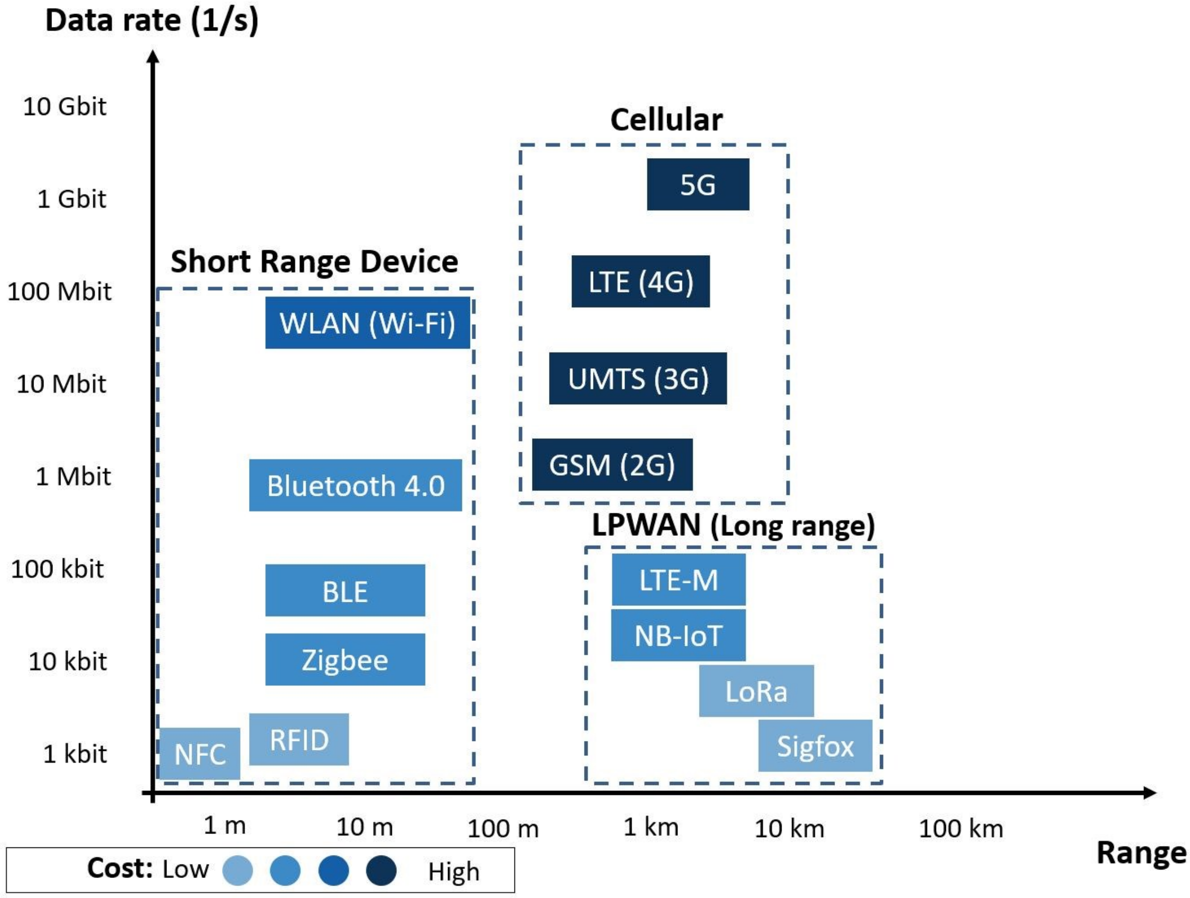


Figure 8: Characteristics of the different funk technologies (modified) [39]

IoT technologies have a long-range compared to RFID. Meanwhile, the Long Term Evolution for Machines (LTE-M), Narrowband Internet of Things (NB-IoT) systems have a long battery life (up to 10 years), due to their low energy consumption [40].

The battery-free NFC smart cards are designed to last ten years. The robust passive UHF RFID tags are battery-free, cost-effective and last practically forever, which makes them appealing [18], [41].

2.3.8 Standards and Norms

The most significant international standards for RFID include ISO/IEC 18000-1:2008 and ISO/IEC 18000-6, which define the air interface for RFID systems in different frequency ranges [44]. The other standards for currently essential uses are illustrated in *Figure 9*.

Norm	Kriterium
ISO/IEC 7810	ID-Cards
ISO/IEC 10536	close coupled cards
ISO/IEC 14443	proximity cards
ISO/IEC 15693	vicinity cards part 1: physical characteristics part 2: radio frequency power and signal interface part 3: anticollision and transmission protocol
ISO 18000	Part 1 Part 2 Part 3 (Mode 1, Mode 2)
ISO 18001	Item Management
ISO 11784/11785	Animal Identification
ISO 10374	Freight Control
ISO 15960	Item Management
ISO/IEC 10373-7	Identification cards - Test methods Part 7: Vicinity cards
ISO/IEC 13239	Information technology – Telecommunications and information exchange between systems – High level data link control (HDLC) procedures
ISO/IEC 7816-5	Identification cards – Integrated circuit(s) card with contacts – Part 5: Numbering system and registration procedure for application identifiers

Figure 9: Important ISO standards for RFID [42]

2.3.9 Status Quo RFID and IoT Technologies

RFID and wireless IoT technologies are widely used in industry, and new innovative solutions and technological developments are constantly emerging [43]. Market research considers RFID technology to have great economic potential and states that it is one of the key technologies in the connected world, having high economic potential for the global economy. Market research institutes, for example, predicted a turnover of 21.90 billion US dollars for the worldwide earnings with RFID transponders by 2020 [44].

Currently there are currently about 90 German manufacturers of RFID systems. "Especially because of trends such as the Internet of Things or the digitalisation of production processes (Industry 4.0), RFID technology will become increasingly important and, therefore faces a flourishing future." [45]. Indeed, the IoT is a promising technology of the future, due to which digital and physical things or objects (e.g. mobile devices, machines and tools) can be interconnected through appropriate information and communication technologies in order to enable a range of applications and services. [34].

2.4 Research on Digital Twin

2.4.1 Definitions and Terms

The term "Digital Twin" describes the continuous maintenance of the digital image of a product by evaluating sensor information to make statements about the condition of the product at any time. Many applications will emerge if the Digital Twin concept is transferred to the building industry. According to buildingSMART, BIM is a basis for the development of digital twins in construction [3].

2.4.2 Components of the Digital Twin (DT)

According to various studies the digital twin concept must consist of five components (dimensions):

1. **Physical part:** The physical part is the basis for the virtual part
2. **Virtual part:** The virtual part reflects the physical part in a controlled set-up
3. **Connections:** The connections provide for data transfer and control
4. **Data:** Data drives services to improve the system's user experience, reliability, and productivity.
5. **Services:** Services must be provided by a DT, for example, simulation, decision making, monitoring and control of the physical object.

A digital twin is a virtual representation of a physical asset [46]. A BIM model is not a digital twin, but a BIM model is a digital representation of the physical functional properties of a structure. The difference between the digital twin and BIM is illustrated in *Figure 10.*

Elements	BIM model	Digital Twin
Physical part	O	✓
Virtual model	✓	✓
Connections between physical and virtual models	O	✓
Twin relationship between the physical part and the virtual model	O	✓

Figure 10: Differences between Digital Twin and BIM [46]

In this table, "O" means that the element is optional, while "√" means that the element is mandatory [46].

“The BIM methodology covers the design, construction and operation phases of a facility. However, a digital twin often includes broader concepts that can focus on very large-scale facilities and integrates information from other sectors. It can be used in the construction sector as well as many other sectors or systems, such as water systems, waste systems, power systems, etc.“ [47]

2.4.3 Status Quo Digital Twin

In the next few years, the use of digital twins in the industry will increase. "For this, new platforms must be created, and still open questions about standardisation, data sovereignty, data security, rights of use, warranty claims, etc., must be clarified." [48]. Today, digital twins are used, in for example, smart manufacturing, automotive industry, supply networks in logistics and transport, construction, cities and infrastructure for real-time simulation, optimisation, quality improvement, and sustainability.

According to Gartner, digital twins are one of the top ten strategic technology trends with expectations of medium-term global market volumes of billions of euros annually. By 2020, it was estimated that 21 billion sensors would be connected to digital twins [49]. “A major challenge in creating the digital twin of a city is the processing and connection of the numerous sensor data of different sources and qualities.“ [50].

2.5 Research on Application Frameworks

2.5.1 Overview

Digitisation is in rapid technological progress and new tools or frameworks for the further development of the software or/and applications are constantly emerging. With help of these applications digital assets are interconnected with hardware. For each project it is important to make the right choice for the appropriate technology. In this thesis, the basics of the existing applications and their features and cloud solutions for BIM were investigated.

2.5.2 Native and Hybrid Mobile Applications

There are differences between hybrid and native mobile apps. “The native applications are platform-specific, so a separate application is required for each platform. This requires a lot of resources and is the reason for developing hybrid applications. A single hybrid application can be used on all devices, regardless of the platform or device type (smartphone or tablet). Hybrid applications or cross-platform applications are a flexible solution.”

In one research paper [51], Apache Cordova tools were used that used cross-platform or hybrid applications. Application development was done in Visual Studio environment that includes tools for Apache Cordova. Hybrid apps are not fully native apps, as they run as web apps within the web view of the device.

Cordova provides extension of JavaScript capabilities with its plugins. Plugins are an integrated part of Cordova system. They provide an interface for Cordova and native components, in order to establish mutual communication and relationships with the standard API of the device [51]. Tests were performed as part of a project for the hybrid and native app under real-world conditions during development for system response, CPU and RAM utilisation. The graphical representations show that, when running native Android apps, the CPU load is significantly lower compared to the hybrid app. These results are to be expected, since hybrid application consume more resources than native application [51].

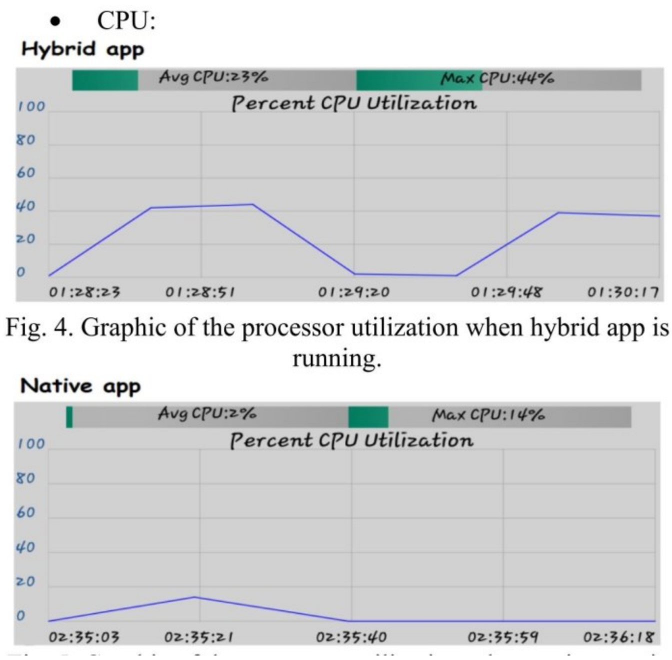


Figure 11: Graphic of the processor utilisation when hybrid and native app is running (Source: Bosnic, Papp) [51]

"After completing the test results, the advantages and disadvantages of native and hybrid applications were compared. The advantage of creating hybrid applications is that multiple platforms can be developed from a single code base. But optimizing the speed of hybrid application is the problem, as it achieves low performance compared to native application. Apache Cordova tools are suitable for hybrid applications that are not very complex or require less functionality. For complex applications, native applications take precedence.

There are certain limitations to be considered when developing hybrid applications.

- The performance of hybrid applications is slower than that of native applications,
- Optimization of hybrid applications is more difficult,
- The screen response time is slower" [51].

Developing native applications for any platform or platform version would impose additional requirements on designers and developers. Each additional requirement leads to new testing requirements. Testing is performed for each platform version. If the application supports three mobile platforms, the application development effort triples [51].

2.5.3 Project about the Cloud based BIM-Platform

The objective of the platform is to design a data as a service system in the cloud for collaboration on a BIM model.

A system diagram is shown in *Figure 12.*

There are two major components in the BIM and an interface for communication platform:

- A database system (MongoDB) was used to store, upload, update the BIM models.

- The interfaces follow a standard protocol to perform those actions upon the database system using CRUD operations (Create, Read, Update, and Delete).

The following sections explain why such a database system provides a good alternative for storing a BIM model, and how to work on a BIM model using database operations [52].

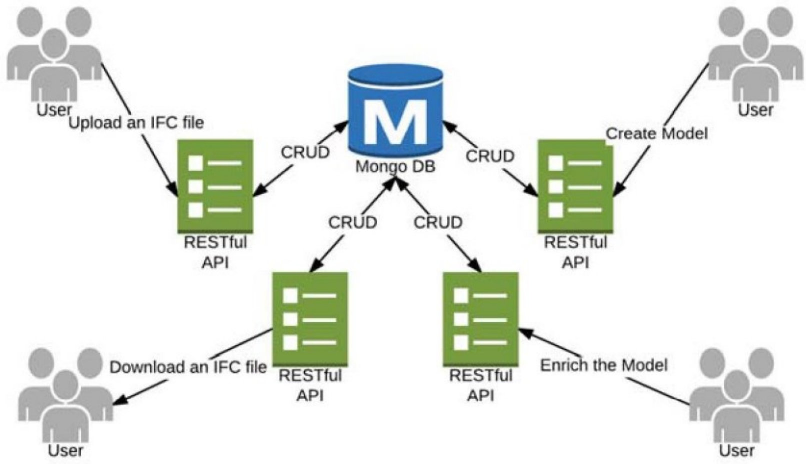


Figure 12: System Diagram of the Cloud Based BIM Platform [52]

“One of the most popular NoSQL database is MongoDB , which is used in the proposed BIM platform. It is a document oriented database, and combines the best of relational database with the innovations of NoSQL technology. It stores the data in its featured Binary JavaScript Object Notation (BSON) format. The basic atom in MongoDB is called document.

Another benefit of using MongoDB is that it uses timestamp-based concurrency control, which is a nonlocking control mechanism, so that it supports real-time read that will not conflict writes and high-speed logging. It has caching and high scalability, which allows running thousands of machines with distributed data, and is well-suited for deployment in the cloud. Sets of redundant servers called “replica sets” help maintain the system availability and data integrity even if individual cloud instances are taken offline. As a result, the NoSQL-based MongoDB system serves a very good alternative for BIM application in terms of easy-to-use among different users.“ [52].

An Application Programming Interface (API) is used to allow one software/service talk with the other. Another term, i.e., Hypertext Transfer Protocol (HTTP) is the standard protocol that defines how a web browser and a web server communicate with each other. For example, the client sends a request to the server and the server sends back a response. As technology moves forward, network-based software architectures have been widely adopted. Hence an architecture called REpresentational State Transfer (REST) […] was proposed to define an API that uses HTTP for a series of constrained methods, such as get, put, post, or delete [52].

When calling one of the API URLs, the method with which the API is called must be also specified, the available methods are the following [53]:

GET – for requesting data

POST – for adding new data

PUT – for updating existing data

DELETE – for deleting data.

Such kinds of API are usually called RESTful APIs. “Many RESTful APIs send responses in JSON, which is both human and machine readable. Another advantage of using RESTful APIs is that those HTTP methods can be easily mapped to the CRUD operations in a database like MongoDB. The RESTful API is a lightweight, standard-based, and platform/language-independent API, which makes execution of operations on BIM model easy.” [52].

2.5.4 Development of Beacons and BIM-based Navigation App

This research uses "Path Finding Algorithms“, which is a simplified approach to obtain real-time indoor location information using a beacon via the developed app „Find Me!“. The main objective of this project is to develop an indoor orientation app that uses Bluetooth beacons for location and BIM for physical contextual information.

The user can specify the destination room in the app as soon as its current location has been determined by the beacons installed in the building. The app uses a path-finding algorithm to calculate the shortest path between the current location and the destination. The calculated route is displayed on the map and gradually updated when a new beacon is read; this continues until the destination space is reached. If the user decides not to follow the suggested path, the app recalculates the route to the selected destination [30].

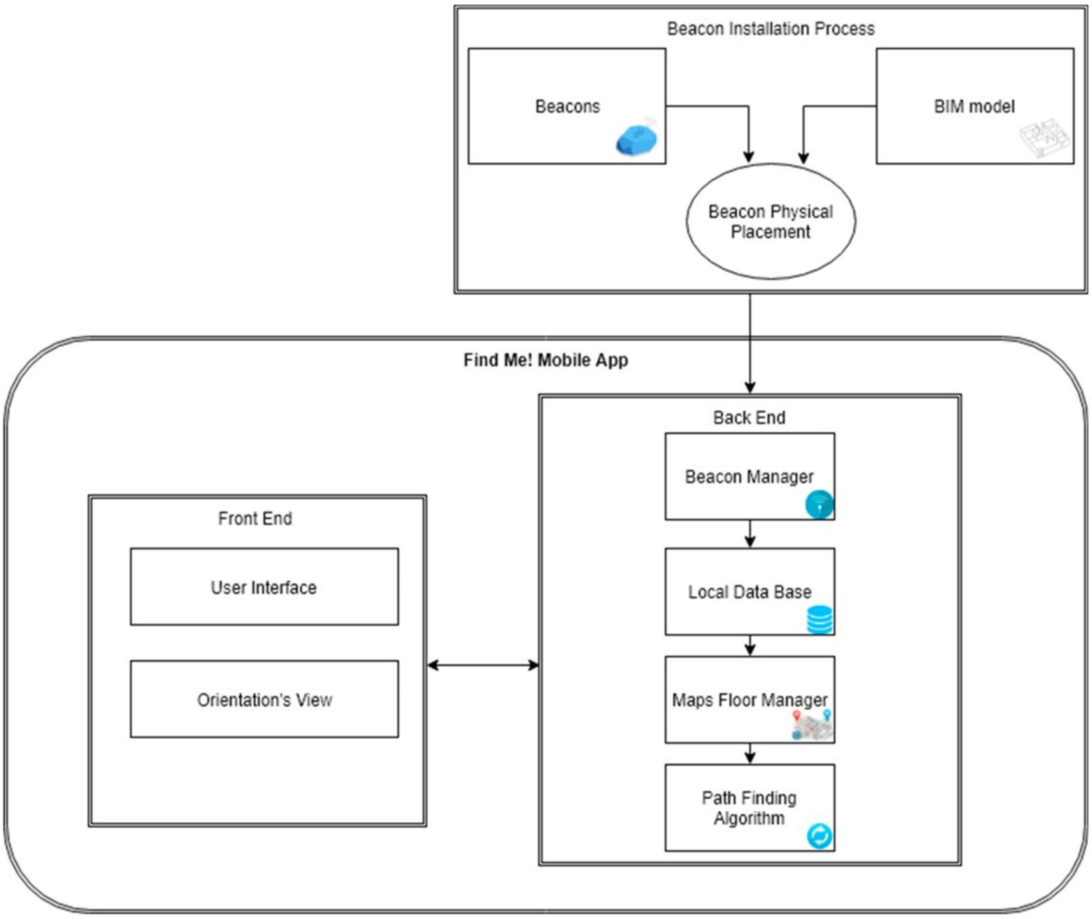


Figure 13: Architecture of mobile app "Find Me!" [30]

The "Find Me!" app project consists of three main system modules, shown in *Figure 13* and is described below:

- **Beacon Installation Process:** The initial installation starts by finding the minimum number of beacons and their location considering the facility layout extracted from the BIM model. The beacons must be configured, placed in the facility and inserted in the BIM model.
- **Frontend Mobile App:** The user interface (UI) side, where the user inserts the destination, configures options and receives dynamic orientation, a map with the optimised path containing crucial orientation photos in order to confirm the user is in the right way.
- **Backend Mobile App:** Contains a local database that stores beacon and room location, automatically extracted from the BIM model. The Beacon Manager scans for beacons and manages data from each intersected beacon signal. The Map Manager manages and configures the map(s) returned to the user interface. Beacon, room, stair, and elevator location, as well as map images are generated by the BIM model and stored locally when the app is installed on the user's smartphone. The Path Finding Algorithm calculates the shortest path between the user and the destination [30].

2.5.5 Other Framework Technologies and Development Environments

Many other development environments provide helpful tools for all programming languages and platforms (frameworks). To achieve the development goals, these tools must support concrete data references and sources in order to process the project's data, content, functions. Therefore, an analysis of the technologies, before the development phase, is essential.

Other development environments include, for example, Google ARCore [54], Unity [55], Unreal [56], Android Studio [57], iOS [58], which are applied for the development of a native app.

“The web represents the most stable and time-tested universal runtime in the world. And today, the web is powering a growing and diverse set of applications—from traditional mobile and desktop apps to Progressive Web Apps, wearables, and IoT devices.” [59].

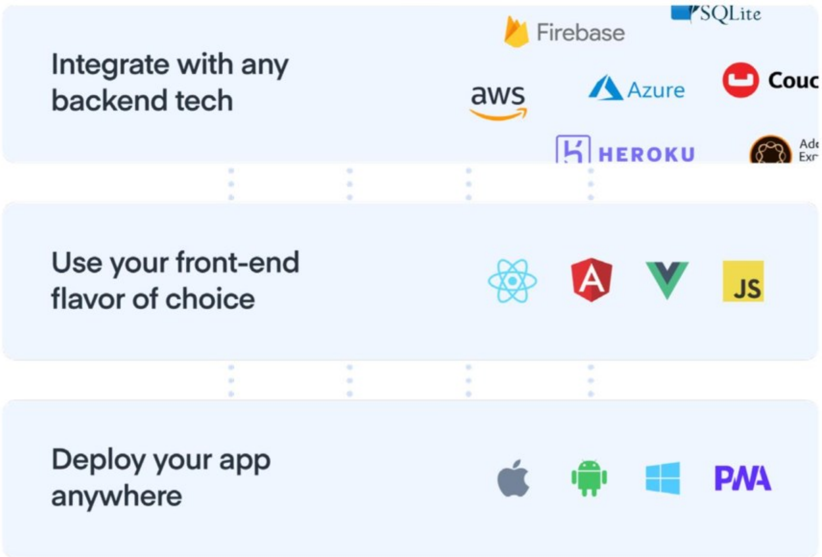


Figure 14: Why Hybrid? - Write once, run anywhere (Source: Ionic) [59]

The hybrid applications, created with open web technologies, such as HTML, CSS, JavaScript, etc., can be launched in the cloud platform as a service including. These include Heroku, Firebase, Azure, Digital Ocean and etc. (see *Figure 14*).

2.6 Research on Positioning Technologies and Methods

2.6.1 Overview

There are various positioning technologies and methods that can be used to develop a navigation and orientation system (also called location system) based on geo-coordinates for indoor and outdoor positioning, path network generation and routing.

The terminology is distinguished as follows:

- **Positioning technologies:** Radio waves, Bluetooth, beacon, tagging (QR code and camera, RFID NFC), inertial sensing.
- **Positioning methods:** Wi-Fi Fingerprinting (point detection, calibration), Trilateration, Pedestrian Dead Reckoning (PDR).
- **Navigation system:** Indoor path network generation, routing and path finding.
- **Information system:** Definition of requirements and use cases, visualisation, data modelling.

2.6.2 Research on Innovative Navigation and Positioning Systems

a) IoT for Integrating Environment and Localization Data in BIM

Digital transformation is a permanent challenge in construction. Facility management, central data collection, storage and planning with BIM in real-time offers many advantages, such as environmental and localisation of workers data in indoor spaces. In order to integrate environment and localisation data into a cloud-based BIM platform for a project at the Ruhr University Bochum (RU Bochum), a concept of constant availability of current performance data through IoT was presented. The project aimed to create a concept for the implementation into existing systems with regard to the prototypical use cases using IoT technologies and "lean and injury-free construction (LIFE)" approach. The study estimated that 80% of the total building costs are incurred in the operation and maintenance phase. Furthermore, the study showed that a seamless link between the early project phases and the operation and management phase is essential to look at the actual life cycle costs of a project [34].

The architecture of this prototype with the associated components is presented in the project by Teizer in *Figure 15.*

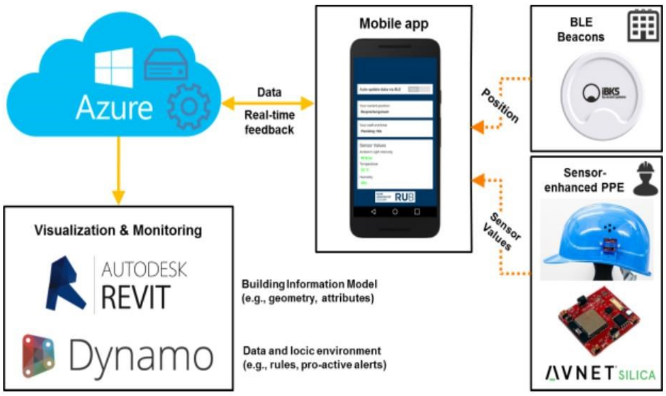


Figure 15: IoT including sensors for data collection, cloud platform data storage, processing, and communication [34]

Below are listed components of the prototype:

- A specially designed 3D-printed box was installed on the side of the helmet, and the sensor (Visible Things Bluetooth Smart Sensors by Avnet) was placed in the box. Such sensors collect various data sets such as temperature, humidity and lighting.
- Application of a simple location tracking device, based on BLE beacons (Accent Systems iBKS105), using the EddyStone Protocol and RSSI measurements for distance estimation.
- A Bluetooth Low Energy (BLE)-based sensor technology to collect relevant data.
- Development of a mobile app (using the Android 6.0.1. application) and internet connectivity of smart devices (e.g. smartphones) for data collection and forwarding data to the cloud platform in real-time.
- In backend, data storage on various IoT platforms (PTC Thingworx and Microsoft Azure's IoT platform) was used in conjunction with Autodesk Revit and the Dynamo programming interface to process real-time data. Azure Cloud only stores simplified data that can be used for further analysis.
- Development of Dynamo script to visualise the results in real time in Autodesk Revit.

The results of the RU-Bochum case study demonstrate that the reliability of the available data collection infrastructure, data evaluation, and communication approaches need to be further investigated. Developing an IoT approach that integrates environmental and localisation data into a cloud-based BIM platform was proposed [34].

b) BIM and cloud-based real-time RFID indoor localisation

Another case study investigated the framework for the BIM and cloud-enabled RFID indoor localisation system for construction site monitoring. *Figure 16* shows a system framework consisting of three components: (1) a RFID indoor localisation system, (2) a BIM-enabled system for project system configuration and data visualisation, and (3) a cloud computing system for data processing and sharing. The RFID localisation system in this study is composed of the following five components: a RFID Reader, RFID Antenna, a passive RFID Tag, a Wi-Fi Router and a local computer with monitoring and alerting tool [60].

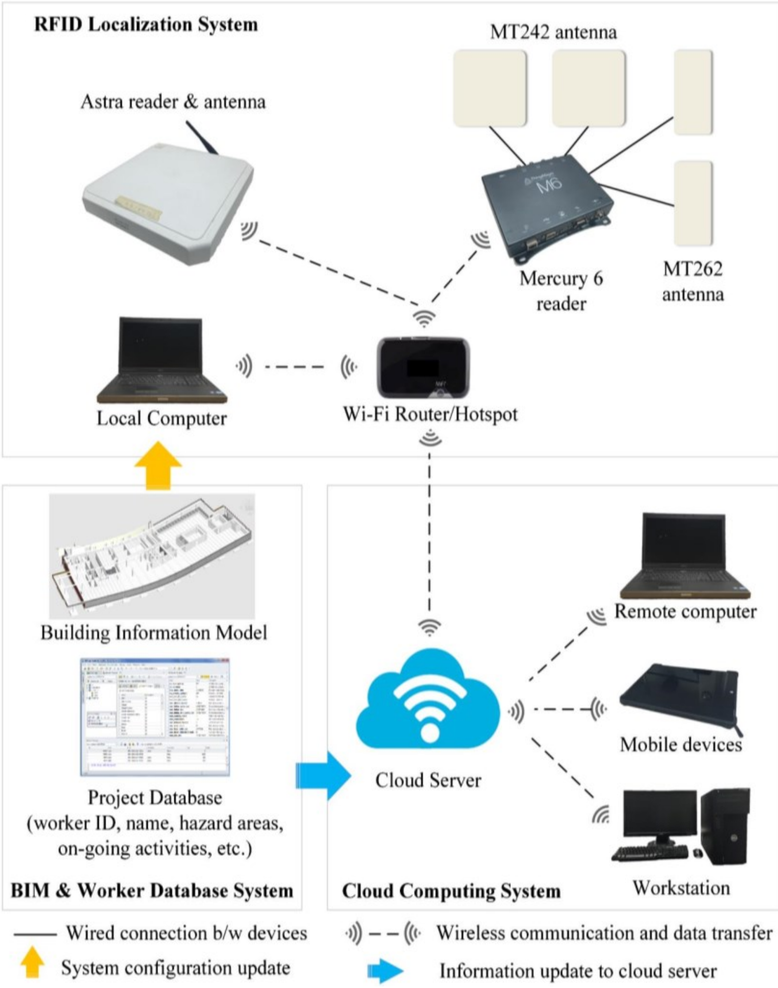


Figure 16: Framework of the BIM and cloud-enabled RFID localisation system [60]

“The cloud computing system is composed of a Wi-Fi hotspot, a cloud server, and client devices. The Wi-Fi hotspot receives location data from the RFID localization system and pushes the data to the cloud server through the internet. The cloud server provides service in the concept of software-as-a-service (SaaS). A dedicated program on the cloud server processes and links the location data with the project database. It also monitors the working status of the RFID localization system. The SaaS requires setting up the program and the database on the cloud server in advance. In addition to the database, floorplans generated from the BIM model are integrated in the cloud server to provide contextual location visualization. BIM serves as essential visualization component in the real-time monitoring application." [60]

c) Combination of WSN and RFID Technologies for Robot Navigation

In a research project in Japan [61], the combination of the contextualised WSN and RFID technologies was investigated in indoor environments with a mobile robot. The goal was to use the advantages of both technologies to improve the speed of indoor mobile robots. A WSN-based navigation system allows a robot to move at a higher speed than a pure RFID approach, although the accuracy is lower. Conversely, RFID technology can provide high levels of accuracy, but the robot must move at a slower speed to ensure that all tags can be read [61].

RFID technology is good to use for tracking objects and navigation. A passive RFID system generally contains a reader, antennas, and a series of labels (tags). For this research, the relatively compact and inexpensive mid-range reader module from Texas Instruments was chosen, which operates in the 13.5 MHz frequency range. The antenna was mounted on the underside of the robot. As the robot passes the RFID tags, it can simultaneously read multiple RFID tags within 5 cm vertically and 10 cm horizontally from the centre of the antenna as the robot passes the RFID tags. The serial number of RFID tags read by the antennae is matched against a table in which the suggested direction is stored. RFID tags, unlike WSN systems, do not offer a direction [61]. RFID tag configurations can be placed in the substrate in strip and radial form (*Figure 17*).

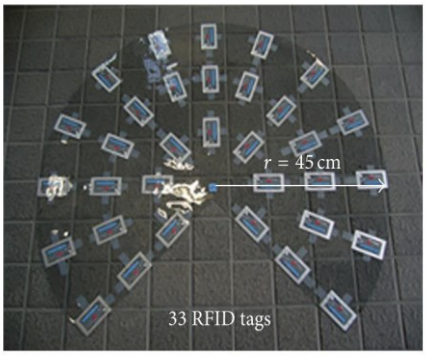


Figure 17: RFID tag mat: prepackaged radial deployment [61]

In this study the radial structure was chosen because of its versatility. Here, the RFID tags were inserted in an arc shape over 90° or 270° with a distance of 15 cm from each other to ensure that the robot can read at least one tag. The WSN system conceptually tells the robot the direction of the target. On the other hand, the RFID system conceptually alerts the robot to obstacles [61].

d) Smart 3D indoor positioning

In an Austrian research studio (RSA iSPACE) an approach was taken to provide buildings as contextual information in a GIS and integrate indoor positioning (IP) information [28].

The approach essentially consisted of two components:

(1) The building's modelling

With regard to indoor positioning in buildings, the challenge, in this project, was to build mapping tools, since the existing plans were in a CAD format, which focuses on lines. To render the data usable for a GIS in an IP context, the objects must be transformed, provided with attributes and verified. Building models can be used for example in standards BIM, geodomains, like CityGML and IndoorGML, and other domains like IFC.

(2) The application of positioning methods.

Bluetooth Low Energy (BLE) for smartphones via a BLE chip and "beacons" (small BLE devices that send their ID and, thus, allow conclusions to be drawn about their own position when the ID is compared with a database) were used [28].

Positioning:

The following components are required to implement Bluetooth positioning:

- “Smartphone-App: Performs the positioning and forwards the data to the data/event handler […].
- Beacon database: Contains all relevant information (e.g. advertising ID, position) about the beacons and is queried by the smartphone app.
- Data/Event Handler: Receives the sent data from the smartphone app, processes it and outputs it to the server in a GIS-readable format.
- Server components: The server can stream the data directly and display it in real-time and/or archive it in a database.” [28].

The Smartphone-App then visualises the Bluetooth’s position and the building, in combination with beacons from various manufacturers, in context, in order to provide the most comprehensive information possible (e.g. surrounding buildings, humidity and temperature measurements).

2.7 Research for Use Case 1 - Barrier-Free Navigation System

2.7.1 Overview

The integration of RFID technology into guidance systems for the blind is already being researched internationally and has also been partially implemented in practice. But previous projects have not yet included BIM components. Although blind and visually impaired do not actually see a BIM model in mobile devices, the primary data of BIM models can be developed barrier-free for the purpose of navigation and positioning systems, not only for the blind and visually impaired, but also for persons with general mobility impairments. Some research projects have been carried out in the field of electronic navigation systems for blind and visually impaired persons, which will be discussed in this chapter.

2.7.2 Facts and Figures

According to the Federal Statistical Office, there were approximately 600,000 blind and visually impaired people in 2019 in Germany. However, WHO estimated the figure to be closer to 1.2 million. The number of visually impaired people is four times higher than that of blind people. One in three seniors over 65 is affected by vision loss. Ninety percent of visually impaired persons are older than 65 years [64]. Statistics from the European Federation of the Blind give the following facts and figures about blindness and visual impairment (see *Figure 18*) [62].

Figure 18: Facts and Figures regarding Blindness and Partial Sight (Source: European Blind Union) [63]

2.7.3 Navigation Systems for People with Limited Mobility

Numerous technologies for the blind and visually impaired have been developed as electronic navigation systems for outdoor and indoor use, such as RFID, GPS; [64], [65] ,[66], [67], [68],

[69]. The literature analysis shows that GPS is mainly used for outdoor areas and RFID technology combined with Bluetooth for indoor buildings.

Guiding Systems for the Blind in Outdoor Areas

Loadstone GPS is an accessible, affordable and portable satellite navigation system used by over 7,000 blind or visually impaired people worldwide. It was developed by blind people for blind people as a turn-by-turn voiceover navigation feature and now runs on IOS-13, Symbian and Nokia S60 operating systems. The platform uses a GPS tracker, a screen reading application and the OpenStreetMap project to plan routes [70].

Mobile Geo, which runs on Windows mobile smartphones, includes a screen reader and technology integrated from previous Braille navigation products. Mobile Geo GPS allows users to track their location and nearby points of interest (POIs), plan a route between specific origins and destinations, and receive instructions on manoeuvres via waypoints along a route [71].

The positioning and navigation system's features for the blind and visually impaired include a simply structured menu, automatic announcements of intersections and information about obstacles, junctions, etc.

BlindSquare is the world's most widely used accessible GPS-app developed for the blind, deaf-blind and partially sighted. Paired with the iOS-based third-party navigation app, BlindSquare's self-voicing app delivers detailed points of interest and intersections for safe, reliable travel, both outside and inside. After determining the location, BlindSquare gathers information about the surroundings on Foursquare and OpenStreetMap [72].

In a completed ZIM (Zentrales Innovationsprogramm Mittelstand) research project of the Technical University of Central Hesse in cooperation with a company Papenmeier GmbH, an outdoor RFID based electronic guidance system was developed for the visually impaired. It provides people with information about their surroundings and has the potential to navigate visually impaired people with the help of a voice-controlled app. The system consists of passive RFID tags with information that is read via an RFID reader in the blind pole and evaluated with the help of a database server. The data is relayed to the user via voice software [73].

Guiding Systems for the Blind in Indoor Areas

The usability of buildings, especially those with complex structures, is limited for people with visual impairments as well as for people with mobility impairments, because navigation within the building without assistance is not possible or difficult. Therefore, there is an urgent need for development with regard to barrier-free building. Electronic guidance systems for the blind can be used to make navigation possible. However, the GPS products on the market today are mainly not used for the orientation of visually impaired users, but are used, for example, in the logistics industry. In addition, due to the current accuracy of GPS of up to 3 metres, GPS data is only suitable for pedestrian navigation to a limited extent and cannot be used in enclosed spaces (railway stations, etc.).

Digital building models could be used to implement a navigation system inside buildings. A software-based working method called Building Information Modeling (BIM) is increasingly being used for networked planning, construction and operation of systems. The universal application of BIM results in building a database that enables collaborative planning between the trades, but can also sustainably support the completion and operation of the building. In addition to the structural properties, the technical, functional and commercial aspects are also mapped by BIM in order to integrate all relevant construction processes. Digital, component-oriented, three-dimensional models form the basis of BIM [74].

2.7.4 Aspects of Barrier-free Accessibility and Sustainable Construction

In recent decades, the principles of accessibility and sustainability with regard to construction have become increasingly important. The guidelines for the sustainable construction of the German Federal Ministry of the Interior, for Construction and Home Affairs (BMI), call for barrier-free accessibility and usability of buildings as a prerequisite for participation in social and professional activities in all phases of life. "The goal is to enable users to use the building without assistance from others. In particular, it is important to enabling people with disabilities to live independently and to participate fully in all areas of life" [75].

Therefore, the user-oriented planning and implementation of a barrier-free-building for people with limited visual, auditory, cognitive or mobility abilities are one of sustainability's most important functional aspects. Accessibility is also required in the evaluation systems for sustainable building (Evaluation System for Sustainable Building (BNB), Certification System by the German Sustainable Building Council (DGNB)) [76].

Accessibility is described in § 4 of the Act on Equality for Disabled Persons (Behindertengleichstellungsgesetz - BGG) as follows: “Structural and other facilities, means of transport, technical items, information processing systems, acoustic and visual information sources and communication facilities, as well as other designed areas of life, are barrier-free if they can be found by people with disabilities in the usual way, without particular difficulty and generally without outside help and are usable. The use of necessary aids due to the disability is permitted.” [77]

The Sustainable Building Assessment System (BNB) is applied to all new federal buildings to be planned or renovated. Some of the BNB assessment criteria are assigned to fulfil the standard of accessibility and its functionality. The aim of the socio-cultural and functional quality of the BNB requirements is to enable better accessibility and freedom of movement for all people in the built environment. In future, the importance of accessibility will increase significantly due to demographic changes in the total population [78].

Integration of RFID technology and BIM planning method in blind navigation systems have socio-cultural and economic aspects. Socio-cultural qualities include user safety, such as consideration of fire safety and accessibility, and an example of a construction-specific aspect is thermal comfort. According to the DGNB definition, the financial characteristics of buildings are determined by their life cycle costs and value retention. The term life cycle costs includes other aspects, such as production costs, maintenance costs (over the defined building life cycle) and construction-specific costs.

2.7.5 Standards and Guidelines

For public spaces, some standards are applied to design tactile floor indicators. These are, for example DIN 32984:2020 (floor indicators in public areas), which are used as a basis for the design of guide strips, attention fields [79] and buildings accessible to the public. The two-senses principle (tactile and auditory perception) is essential according to DIN 18040-1 [80].

The standard DIN 18040-1 describes the general minimum requirements and recommendations for barrier-free construction in publicly accessible buildings [80].

There are standards for public spaces, which apply to the design of tactile floor indicators. These are, for example DIN 32984:2020 (floor indicators in public areas), which are used as a basis for the methods of guidance strips and attention fields. DIN 32984 specifies, among other things, the shape and dimensions of floor indicators in public spaces suitable for visually impaired people. Also specified are the installation process of floor indicators and standard solutions are given for ‘typical’ basic situations [79].

2.8 Research for Use Case 2 - Infrastructure Objects in Urban Water Management

2.8.1 Overview

RTLS and IoT technologies have and are being used for infrastructure objects in urban water management. The aim is to detect and identify infrastructure objects with the help of innovative technologies. Numerous projects were found on this topic in the literature research, which are described in this chapter.

2.8.2 Usage of RFID Technology for Maintenance in Sewer Networks

To regularly check the condition and functionality of sewer systems, a pilot project, "Manhole management using RFID technology", was implemented in the town of Warendorf in 2001. The core of this project was the permanent and maintenance-free explicit tagging of structures (sewer maintenance holes), using battery-free RFID transponders and linking the associated handheld computers (RFID readers) with the existing municipal GIS software from the company Ingrada. When the RFID tag is read with the mobile reader, the data record of the object is displayed [81].

A similar project was carried out implemented in 2009 by Abwasserbetrieb Weimar (AWB), a wastewater company in the German city of Weimar and the company ITS System GmbH. They used RFID transponder-supported equipment maintenance for mobile maintenance and identification of the sewer maintenance holes working with the Smallworld GIS.

The AWB's system contains the following software and hardware components:

- **Data hub:** The Lovion CONNECT and Lovion SYNC modules, as a data hub, enable problem-free data exchange between the Smallworld GIS, the Lovion BIS operations management system containing Lovion WORK and the PDA-based mobile data collection devices (personal digital assistants).
- **Hardware components:** Passive screw transponder with 13.56 MHz and 2 Kbit read and write memory. The "PSION WORK ABOUT PRO" PDA reader (see *Figure 19*). With the introduction of RFID technology in duct systems, sustainable documentation of maintenance and repair work can be made possible, and the collected data can be visualised, evaluated and filtered [82].

Figure 19: Identification of a Manhole using the Built-in RFID Transponder with the help of PDA Reader [82]

“The first implementation step was the installation of the transponders into shafts. This was also the most expensive and time-consuming process. The transponders had to be written with the corresponding data. The GIS served as the basis. The master data was exported to a file via a GIS query, which was carried out street by street or, for example, via an auxiliary line, and then copied to a PDA, which was used to initialise the corresponding transponders in the shafts. The object identification is carried out via a mobile RFID reader with Lovion TASK PDA.“ [82].

RFID-based sensors are not widespread in environmental technology, especially with regard to rainwater and wastewater. A similar study was conducted to develop the suitability of RFID technology for smart monitoring applications in wastewater systems. The study used passive UHF RFID-based sensors to detect sewer blockages in mains (sewer network). The results showed that UHF RFID has excellent reading ranges and can even be used to measure the surface velocity of rainwater and sewage in pipes. This due to the longer ranges and robustness to predict information about blockages in the sewer system. However, suitable passive RFID sensors must be selected for this purpose [83].

RFID technology, particularly ultra-high frequency (865-928 MHz) technology, is used in many industries and large-scale Internet-of-Things (IoT) applications, because to its simple architecture, real-time sensing and versatile sensing ranges. The use of UHF RFID sensors in wastewater systems offers some advantages. They are battery-free, have a long lifetime, are small and cost-effective [84].

New methods are being researched to determine the extent to which RFID technology can be used to improve urban infrastructure and floodplain management [85].

2.8.3 NarrowBand IoT in Sewer Systems

Smart sensors in roadside catch pits and stormwater drains can sense if a drain is full of water and, if applicable, send a signal to indicate that it needs emptying. Along with regular reports, they send an alert when water levels are rising, which could also suggest a blockage in the system [84].

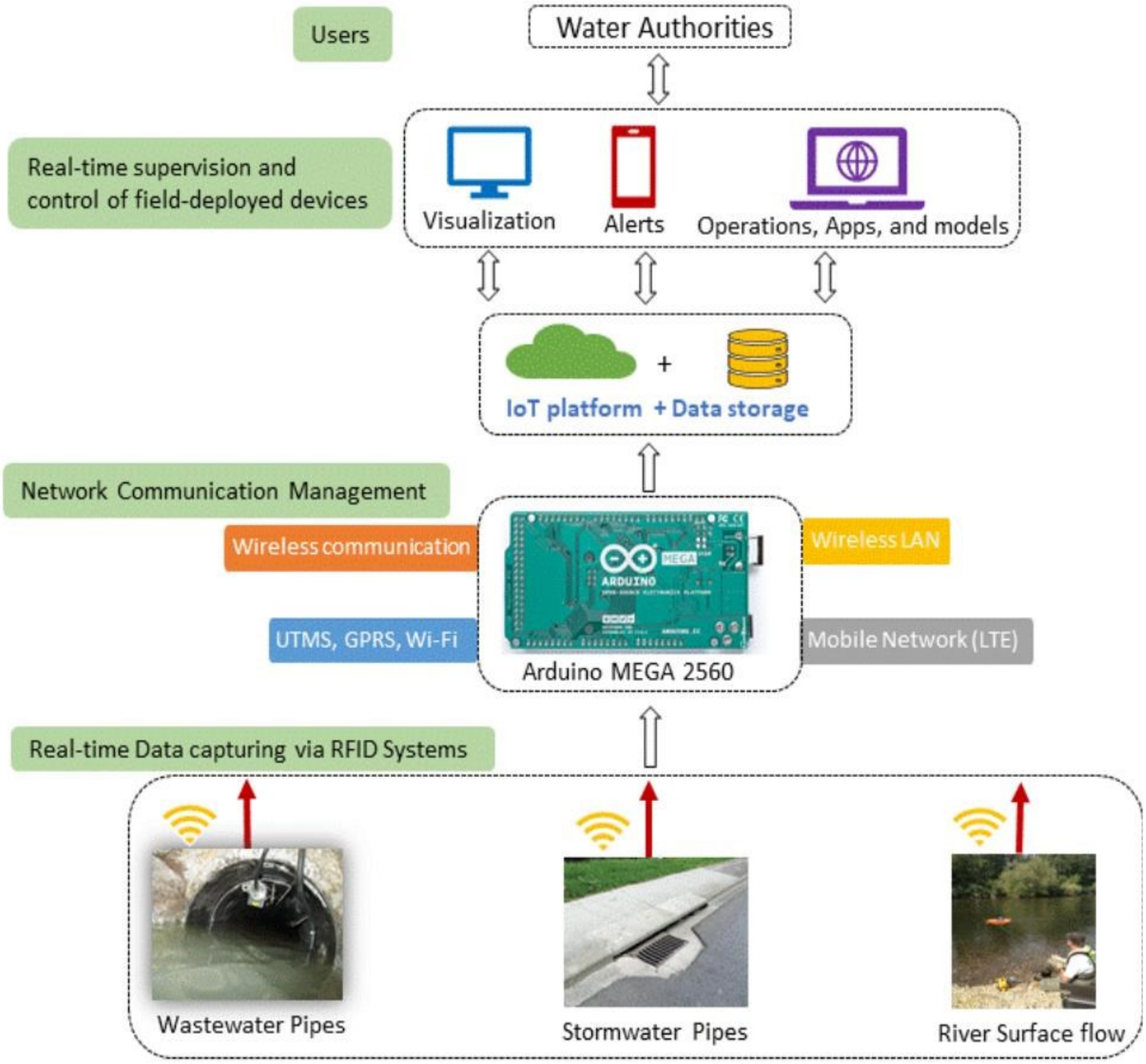


Figure 20: Proposed Framework and Architecture for Real-time Monitoring Applications using RFID Technology [85]

A city council in Victoria, Australia, has equipped storm drains with smart sensors to monitor stormwater runoff in order to improve underground infrastructure [86]. The sensors are connected via NBIoT (NarrowBand Internet of Things), a low-power wide-area solution designed specifically for IoT devices and services [86].

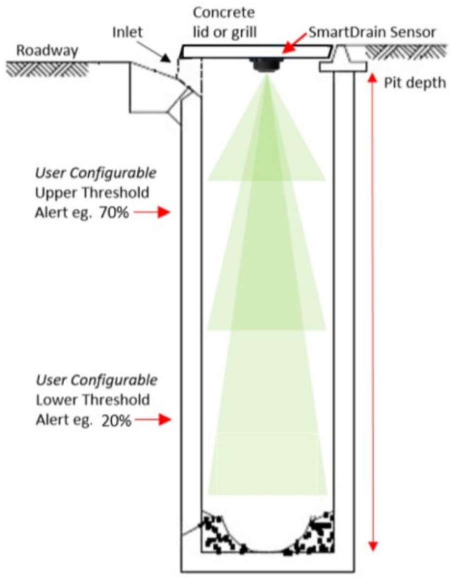


Figure 21: Use of EYEfi Cloud Smart Drain Sensor for Smart Monitoring of Sewer Systems [86]

2.8.4 Project "Smart Sewer Asset Information Model"

Nowadays, various monitoring systems are used in the drainage sewer network. These include, for example, precipitation gauges and water level, water velocity and water quality sensors. Technological solutions used in the drainage network include aerodynamic devices and bio, physical and chemical sensors, ultrasonic level sensors, level and velocity sensors, radar or laser technology and others to detect and prevent pollutants in wastewater. Many of these sensors can be linked to tracking technologies, such as GPS modems or GSM Short Message Services (SMSs), to send measurement data to web-based cloud servers. The sensors usually operate by battery, which has a lifespan of two to three years. The final battery life of the sensor depends on operating temperatures, transmission frequency and data readings [87].

To develop a web-based application in the *Smart Sewer Asset Information Model (SSAIM)* project, IFC4 and GIS-based data architecture were compared. Since many independent components interact with IoT systems, interoperability of the system components is an essential requirement for each part of the network to form a heterogeneous network. Efficient data size and open data schemas are necessary for data exchange.

Figure 22 shows a comparison of the IFC4 STEP 21 data representation, and the ESRI Shapefile is a common method for exchanging GID datasets nowadays [87].

	Original GIS data provided by Northumbrian Water	**SSAIM**
File format	ESRI Shapefile ®	STEP 21 (ISO 10303-21:2016)[48]
File size	95 MB	11.2 MB
Compressed File Size (ZIP)	1.1 MB	1.9 MB
Open File Format	YES	YES
Data Schema	Organization defined	IFC4 (ISO 16739:2013)
Open Data Schema	NO	YES
Documentation	NO	YES

Figure 22: Summary comparison of the data formats GIS and STEP 21 (IFC) [87]

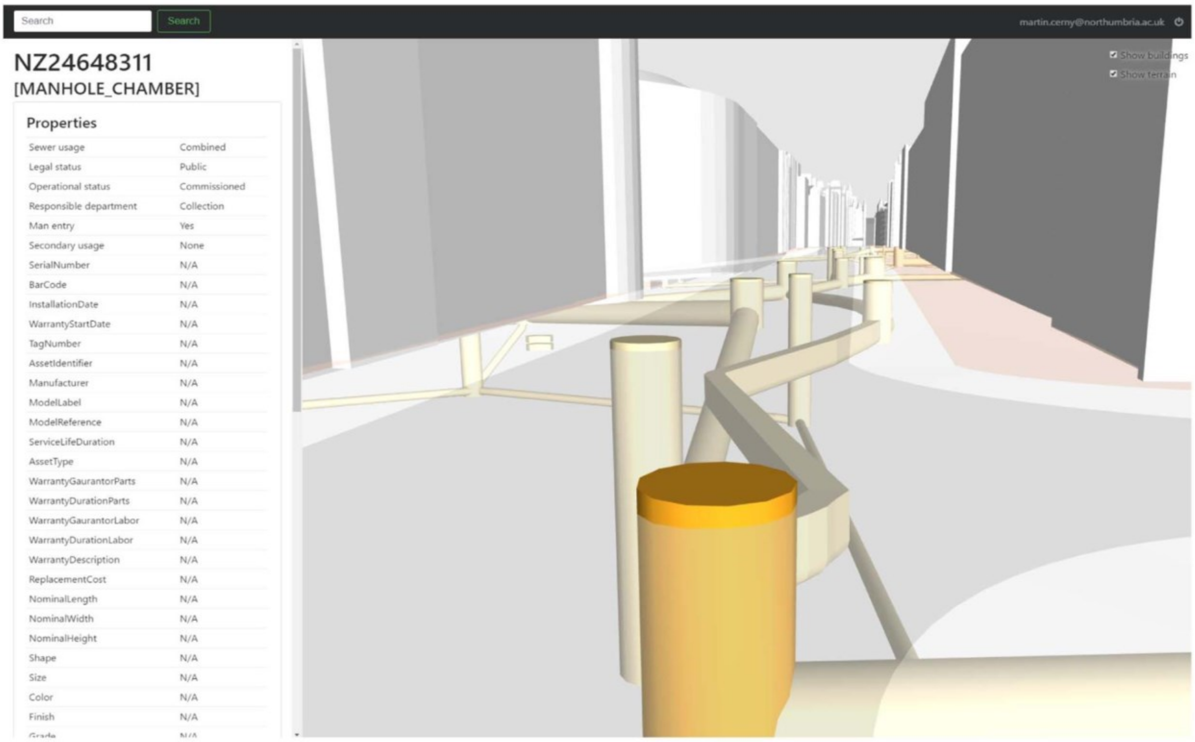


Figure 23: Example of an asset showing the properties dialogue box open, from the SSAIM [87]

The xBIM toolkit was used for the STEP 21 file in a developed SSAIM-prototype web application shown in *Figure 23*. The xBIM toolkit is a .NET open-source software development BIM toolkit which supports the BuildingSmart Data Model (IFC).

The xBIM Toolkit supports the following modern web technologies to create the web application:

- WebGL (HW-accelerated graphics rendering)
- The Angular2 web application framework, HTML5 (a set of JavaScript APIs for advanced data presentation and usability)
- The Bootstrap4 presentation framework
- The OWIN authentication framework

The IFC4-based SSAIM application includes distributed smart sensors that provide real-time monitoring and reporting of the sewer asset performance. To achieve a direct link, the sensor measurement data is mapped within IFC4 to an *IfcPerformanceHistory* class and then to a specific asset entity in SSAIM (e.g. *IfcPipeSegment*). In order for web-based, accessible sensor networks to support open standard OGC (Open Geospatial Consortium), the XML (eXtensible Markup Language) scheme links the sensor data. The results describe an approach for sensor data analysis to facilitate real-time flood forecasting [87].

2.8.5 Advantages of Using RFID and IoT in Sewer Systems

The use of sensors and IoT in sewer systems provide the following advantages [84]:

- The automatic monitoring of rainwater maintenance holes and sewers
- Better maintenance of the sewer network through specific measures in known problem areas
- Opportunity for accurate monitoring and reporting on the performance of the facilities.

2.8.6 Standards and Guidelines

In Germany, in addition to the standards for infrastructure objects in urban water management (DIN EN ISO, DIN EN and DIN), recommendations and regulations of the 'Deutsche Vereinigung für Wasserwirtschaft' (German Association for Water, Wastewater and Waste) (DWA) must be observed. For concrete and reinforced concrete manhole systems, DIN EN 1917 and national supplementary standards DIN V 1201 and DIN V 4034-1 apply. The other standards and guidelines are listed in [88].

3 METHODOLOGICAL APPROACH

3.1 Overview

The integration of wireless technologies for connectivity into BIM systems can provide new opportunities for developing BIM model-based positioning and navigation systems. A prototype application was developed to incorporate physical structures (buildings or infrastructural elements) into a BIM model. This application makes it possible to link BIM models with the help of RFID tags embedded in the structural elements.

The purpose of the software development is to obtain the identification number of an RFID chip (ID or UID) which is integrated into the building materials by the electronic RFID reader via a connection (e.g. Bluetooth). The UIDs of an RFID tag are defined in the BIM model as attributes that enable linking the physical object with the virtual BIM model via the app.

This chapter presents a technical and technological concept, based on the tools identified in the literature research, as a solution. To begin with, the requirements for the prototype application, with consideration of the BIM model, with all backend and frontend, were created. On this basis, the software architecture framework was created. Founded on this, initially, a proof of concept was developed, in which the backend (database, service) and frontend (UI framework) were implemented. The planned technological development is illustrated in the PoC.

3.2 Development of a Concept Based on Design Thinking Process

The design thinking method was used to develop the project in this thesis. The Method is well suited for solving complex problems, which was developed by Tim Brown from California. The objective of the method is to develop innovations that are based on the needs of the users, as well as to show a solution path for a specific problem. At the centre of all considerations is the human being [89].

The identified problems in subchapter *1.1 Background and problem definition* were analysed using this method. Furthermore, literature reviews were analysed. In the literature research, similar projects were found and this project was restricted to the existing technologies. The software and hardware components were studied within the problem-solving process, and a prototype application was developed. At the end, the developed prototype application was tested and an evaluation was carried out.

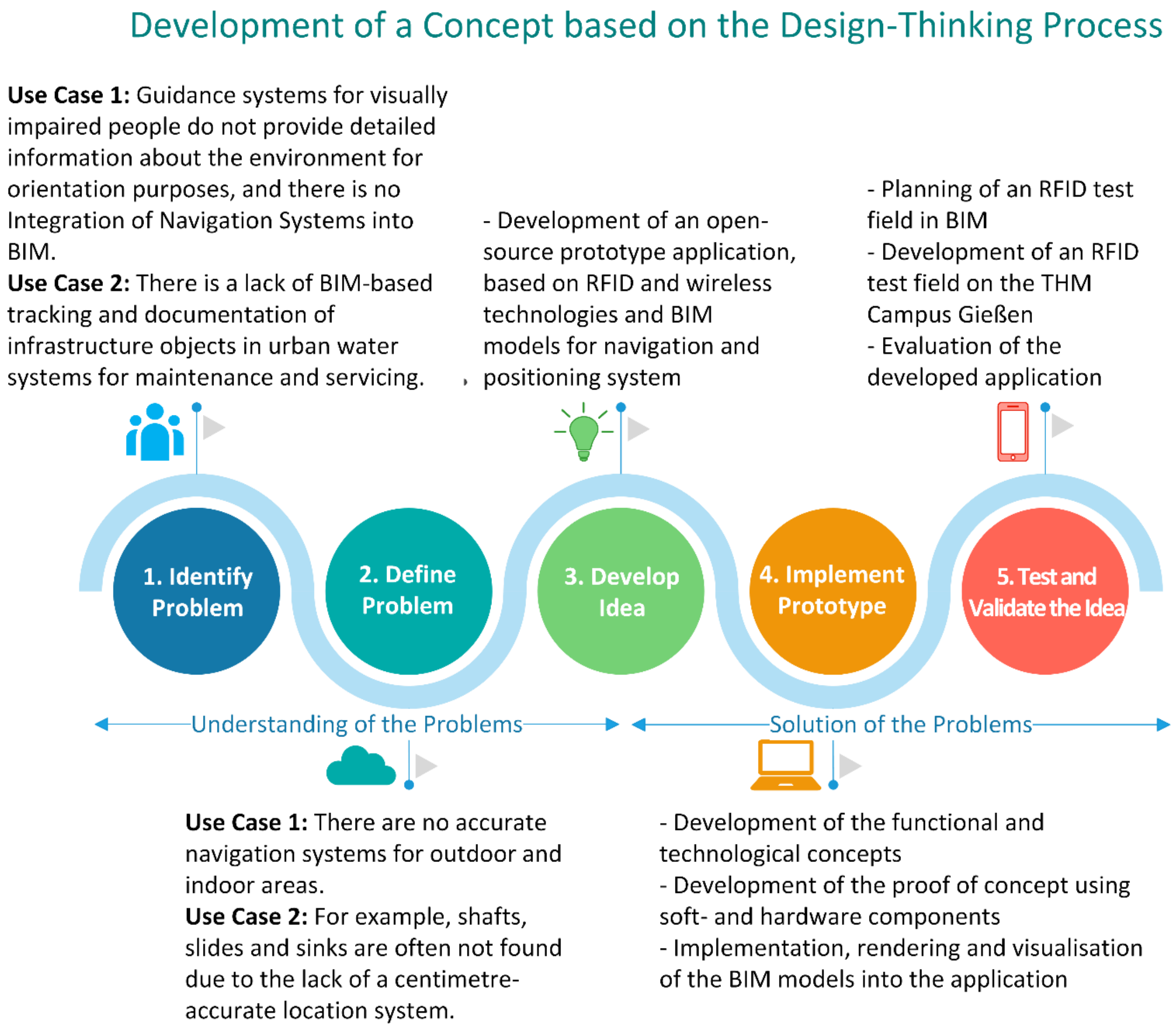


Figure 24: Design-Thinking-Process (Source: A. Juraboev)

3.3 The Technical Concept

The technical concept describes the requirements for the application that will be developed, *openNaviBIM*. For the development of an application, a multi-platform (hybrid) solution was chosen. The reason for choosing a multi-platform application is that this platform can be developed independently from a single code base onto several platforms. Since this work represents a prototypical solution for numerous use cases, the choice of a multi-platform application is a solid approach.

The planned Application *openNaviBIM* will function as follows: The main functionality of the multi-platform application is based on a BIM model's supported positioning and navigation system using RFID wireless technologies. The open-source interface IFC is used, in practice for most BIM planning software and delivers BIM models for further use in other open-source applications. In *openNaviBIM*, BIM models will be provided and maintained by the administrators. The user can download these BIM models and use them for their services.

By reading the objects labelled with RFID tags, the assigned information in BIM models can be recalled and provided to the users in three dimensions in a visible and audible way. For this purpose, an integration of the RFID reader into the application is planned.

3.3.1 Functional Requirements for the Application

The functional requirements for the multi-platform application are as follow:

- The homepage of the multi-platform application *openNaviBIM*: The basic idea is described.
- Choice of open-source software components (framework and database) and the IFC file format (STEP-file, ISO 10303-21), to be used as an openBIM concept.
- Rendering and visualisation of the BIM model using the IFC file.
- Representation of the BIM model in the survey or reference coordinates.
- Operation of the application with zoom-in and zoom-out function.
- Connection of RFID device (reader) to smartphone via Bluetooth function.
- Representation of the property sets (family and project properties) of the BIM model.
- Representation of the layers and properties of the BIM model.
- Representation of attributes of the BIM model (e.g. producer information, audio, etc.).
- Other representations that are relevant for the Use Cases.

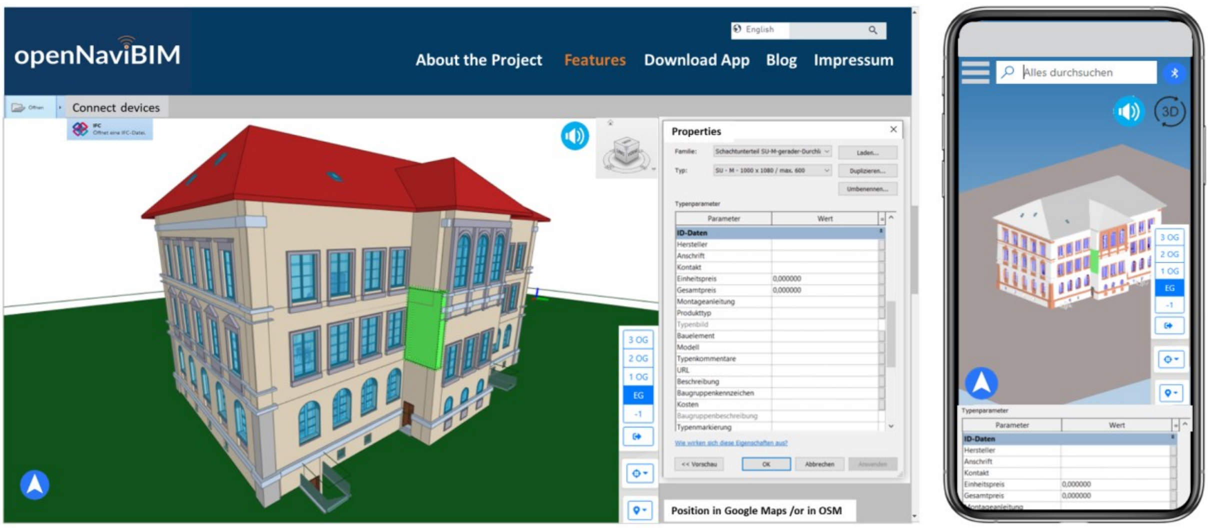


Figure 25: Mockup Design for Cross-Platform-Application Prototyp (Source: A. Juraboev)

3.3.2 Requirements from the User's Point of View

The usage requirements for the cross-platform application, from the user's point of view, are described as follows.

a. From the Perspective of the System Owner (system administrator):

The system owner (admin) provides the BIM models to the *openNaviBIM* platform. The admin can upload one or more BIM models into the *openNaviBIM* via the web application. Depending on the application purpose, the admin can decide which information is provided in the BIM model. The information is defined by the properties in the BIM model during the modelling process.

b. From the User's Point of View (public):

The user can download BIM models for a specific physical structure tagged with RFID. He/she can access the BIM-based information in the app via a smartphone or with the help of an RFID reader. The data is presented visually (three-dimensional BIM model) and in text form (properties of the BIM model), as well as acoustically (audio information).

3.4 The Technological Concept

The technology concept describes relevant input and output data and their functions, and the processing algorithms for the transformation of the results.

The technological development of the system includes the implementation of Software-Solutions and Hardware-Solutions, which are defined as follows:

Software-Solutions:

- Description and development of a software architecture for the project
- Selection of tools and frameworks in an open standard
- Implementation of the mobile app and web applications as a multi-platform solution
- Selection and creation of a database system
- Modelling and attributing the RFID tag as BIM objects in a BIM-based software using the IFC classification system
- Programming and preparation of BIM data in the application

Hardware-Solutions:

- Procurement of the hardware components (e.g. RFID tags, RFID readers, BLE readers)
- Investigation of the incorporation of RFID tags in the production of building materials or objects for various use cases
- Investigation of RFID tags, according to a reading range, in building materials

As part of the prototypical development of the openNaviBIM multi-platform application, the layered architecture of the technology concept was developed. *Figure 26* illustrates the relationships of the components, according to the BPMN approach, in a process map.

According to Costin and Teizer, any conventional BIM software and RFID technology can be connected [90], e.g., using passive RFID and BIM for accurate indoor localisation.

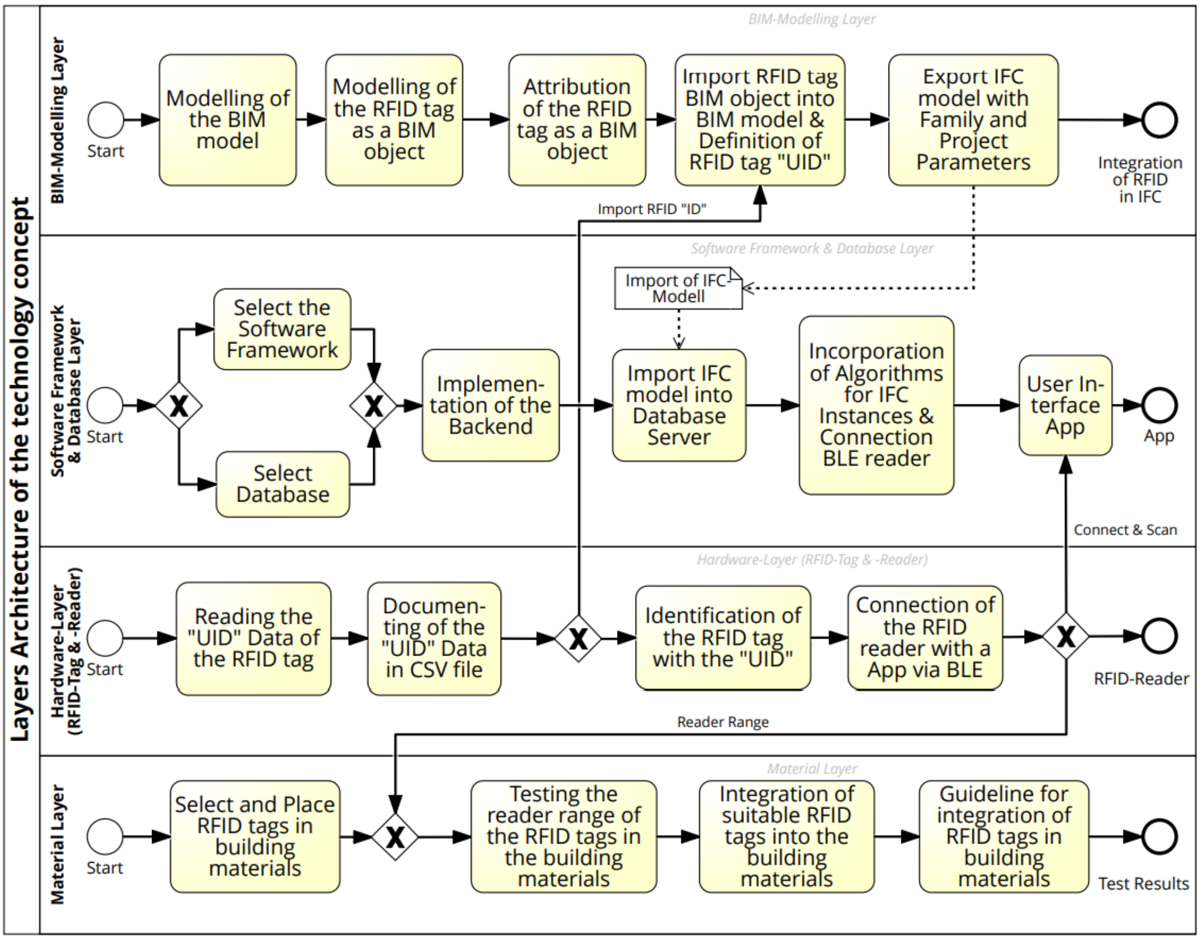


Figure 26: Layers Architecture of the Technology Concept (Source: A. Juraboev)

The various layer components of the technology concept for the development of the BIM-based navigation and tracking system are as follows:

BIM-Modelling Layer: In this project, physical objects were modelled by BIM-supported software. For this purpose, for example Autodesk Revit was used. The RFID tags were modelled as a BIM object and defined with the associated attributes and parameters can be used as an integral part of a BIM model in any project. Parameters include, for example, RFID tag UID, RFID EPC, audio URL, manufacturer information, etc. The BIM model also can be exported as an IFC file.

Software Layer: For the software development, particular value was given to the open-source application and ease of use (usability). The software was developed to identify the identification number (UID) of an RFID chip which is integrated from the electronic RFID reader into the building material via an interface (e.g. Bluetooth) from the electronic RFID reader. The software level consists of the following components:

- **Framework:** The choice of software/application framework is the basis for the communication between RFID, IFC model and database. Particular attention must be paid to ensuring that the IFC models can be visualised in selected development environments in the application. In this project, the cross-browser JavaScript library Three.js was used to visualise and display IFC models in a web browser.

- **Database:** BIM models can be loaded into databases in IFC format. The BIM model can be uploaded to server via an one-time retrieval. Data is not stored in the end device.
- **Algorithms:** IFC data contains a spatial tree hierarchy, for example, the recursive algorithm can be applied.
- **User Interface and Display:** Through the graphical user interface, operations, such as reading RFID tags with an RFID reader, can obtain the properties of the BIM model and view them in a table. The RFID tag "UID" in the BIM model can be used as a link.

Hardware Layer (RFID Equipment: Tag & Reader): Firstly, the RFID chip "UID" should be read out using RFID Control-Reader software (ISO 15693 Reader), and documented as a CSV or Excel file. To avoid confusing the RFID tag’s UID data, the RFID tags should be marked with the read ID numbers. This is necessary for inserting the ID data into the BIM-supported tool.

The tags can be scanned by RFID or PDA scanners using a Bluetooth plug-in via a developed application. Note: Modern smartphones support the BLE Bluetooth version up to 4.0. Therefore, the selected RFID reader must have a suitable BLE Bluetooth plugin.

Material Layer: Laboratory tests, to identify optimal installation patterns and range of the RFID transponders, should be carried out. Suitable ways to insert the transponders into the building materials have to be selected. RFID tags are integrated into different building materials based on the results of the tests.

3.4.1 IFC Spatial Tree

The application to be implemented is based on the open file format IFC (Industrial Foundation Classes), a model file used by BIM programmes. The tree structure of the IFC scheme is very complex and contains many abstract levels that are not visible to the end-user.

Tests were carried out with the BIM model in IFC viewers, such as ‘Open IFC Viewer’ and xbimXplorer. The IFC schema is structured in this hierarchy (*Figure 27*).

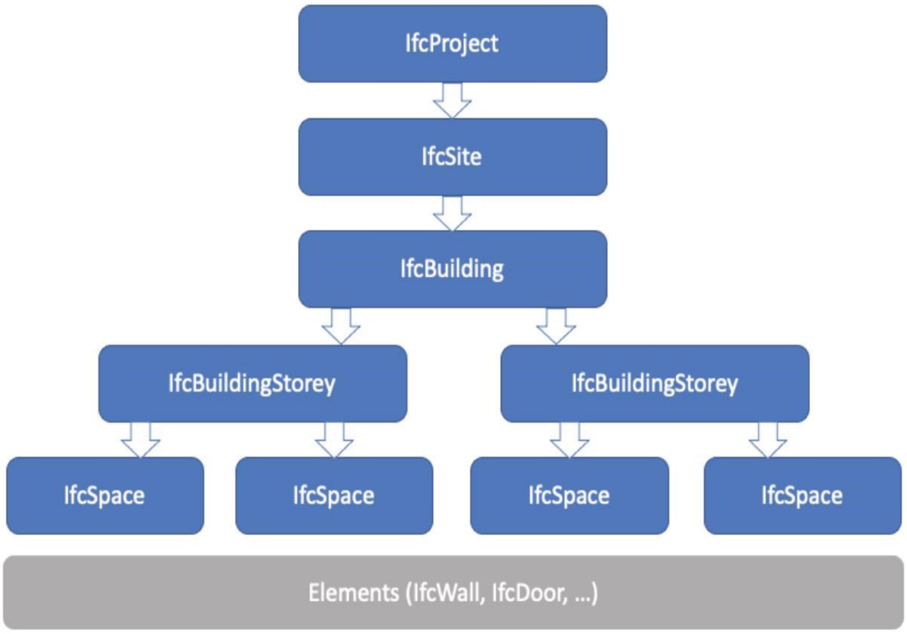


Figure 27: The IFC Tree Structure [8]

In IFC, three main entities (*IfcProject, IfcSite and IfcBuilding*) are represented only once per IFC file.

- IFC PROJECT: Project
- IFC SITE: Property
- IFC BUILDING: Building
- IFC BUILDINGSTOREY: Floor
- IFC BUILDING ELEMENTS: Objects according to IFC classes

„In addition, there are also general IFC classes, such as *IfcBuildingElementProxy*, for undefined, non-standard structural elements.“ [91]

3.4.2 Development Tools for the Environment

The following development tools were applied to the software environment for the prototype application:

- **NodeJs and Node Package Manager (NPM)**

“NodeJs is a cross-platform open-source backend JavaScript runtime environment for developing various tools and server-based web applications. Web servers and network tools can be developed using JavaScript. With the help of package manager "npm", the source code of NodeJs is ready for use in the operating system of the computer.” [92].

Npm is the package manager for software solutions used in the JavaScript runtime environment Node.js. It uses an open-source with freely available repositories for sharing code packages for software development [93].

A repository is a storage folder of stored digital assets. The code packages can be found here and come mainly from npm users to freely provide available software. These packages can be transferred and used within npm [94].

- **Cordova**

Apache Cordova is one of the most popular mobile application development frameworks. Cordova can be used done Cross-platform for development by using various web technologies, like HTML5, CSS3 and JavaScript. It makes more sense to run the same application on multiple platforms using the same code base (‘Code once and Run Everywhere’). Cordova command-line runs on Node.js and is available on npm [95].

“[…] accessor hosts are Browser, Node and Cordova. A Browser host supports executing accessors within the web browser. Accessors are instantiated as HTML pages in a Browser host. A Node host is basically a Node.js engine with support for the common host’s capabilities. A Cordova host is an extension of Apache Cordova’s cross mobile program development platform that is used for building applications using HTML, CSS and JavaScript15 in one code base and targeted to multiple platforms such as Android, IOS, and Browser with no additional programming. The JavaScript interface of the accessor in Cordova interacts with native languages and APIs of physical or virtual IoT devices through a number of plugins. In essence, the plugin hides the various native code implementations behind a common JavaScript interface.” [96]. Plugins are the core part of the Cordova system and act as a standard interface between Cordova and the native components for them to communicate with each other. The plugins allow users to access various components, like the camera, battery, widgets and other media [97].

“There are several components to a Cordova application. The following diagram shows a high-level view of the Cordova application architecture. Web App, Cordova Plugins and Web veiw are connected with Mobile OS.” [98].

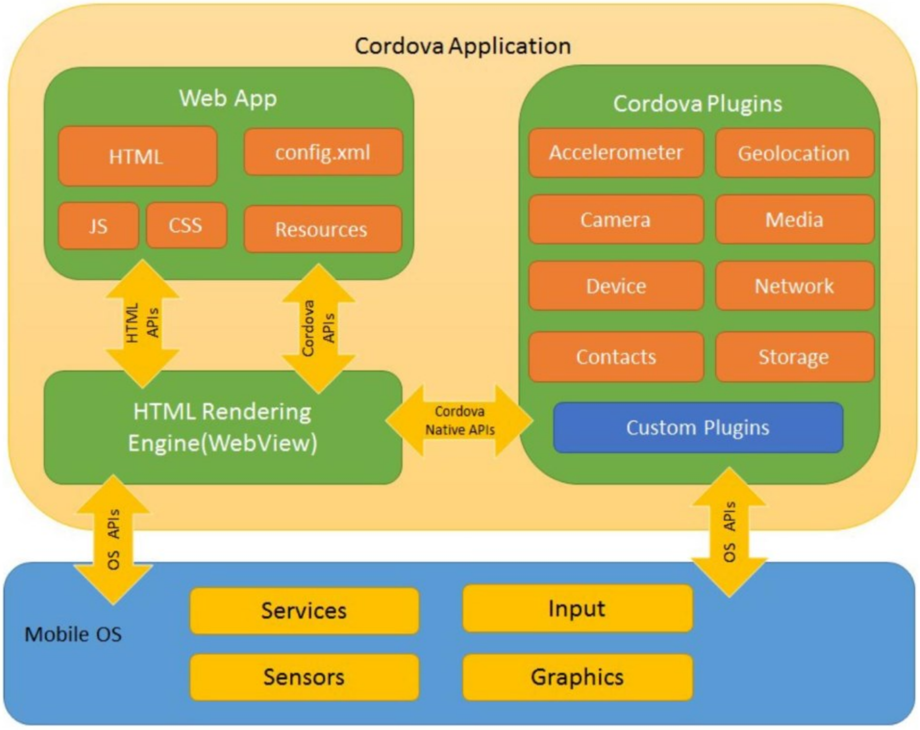


Figure 28: Architecture of Cordova Framework [98]

“The Graphical User Interface (GUI) of different operating systems may be different. A code will be able to run on different Mobile OS when created using Cordova.“ [97]

- **Meteor.JS**

“Meteor is a full-stack JavaScript platform for developing modern web and mobile applications. Meteor includes a key set of technologies for building connected-client reactive applications, a build tool, and a curated set of packages from the Node.js and general JavaScript community.

- Meteor allows you to develop in one language, JavaScript, in all environments: application server, web browser, and mobile device.
- Meteor uses data on the wire, meaning the server sends data, not HTML, and the client renders it.” [99]

For example, using Meteor lets users create apps for any device by using the same code, whether it's developed for the web, iOS, Android, or desktop, to provide users with a seamless update experience. “With Meteor, there is no need to install Cordova yourself, or use the Cordova command directly. Cordova project creation happens as part of the Meteor run and build commands […].“ [100].

- **Object-oriented programming with JavaScript**

The programming language JavaScript has the further advantage that, along with HTML, that is the document description language on which Internet pages are based, it is one of the essential standards currently available for computers [101].

Hypertext Markup Language (HTML) is a web page specified language that deals with a text document to create the structure and design of the web page, and layout of the content [101].

For formatting the style of the web page, such as background colour, font colour, font-family, font-size, etc., CSS attributes (Cascading Style Set Attributes) are used. Also the different screen sizes of the web pages are designed here [101].

- **Git Bash**

At its core, Git is a set of command line utility programs, designed to execute in a Unix style command-line environment. In Microsoft Windows environments, Git is often packaged as part of higher-level GUI applications.

“Git Bash is an application for Microsoft Windows environments which provides an emulation layer for a Git command line experience. Bash is an acronym for Bourne Again Shell. A shell is a terminal application used to interface with an operating system through written commands. Bash is a popular default shell on Linux and macOS. Git Bash is a package that installs Bash, some common bash utilities, and Git on a Windows operating system.“ [102].

- **IFC.js Library for BIM Toolkit**

IFC.js is a JavaScript library, developed by Antonio Gonzales Viegas, for loading, viewing and editing open-source IFC models in the browser. It is a BIM toolkit platform and provides a quick and easy way to visualise IFC files in any browser or mobile device. IFC.js is currently in an early stage of development [103].

- **Three.js - JavaScript 3D-Library**

“Three.js is a cross-browser JavaScript library and application programming interface (API) used to create and display animated 3D computer graphics in a web browser using WebGL. The source code is hosted in a repository on GitHub.“ [104].

Figure 29 shows an IFC model used in ThreeJS Editor for testing purposes.

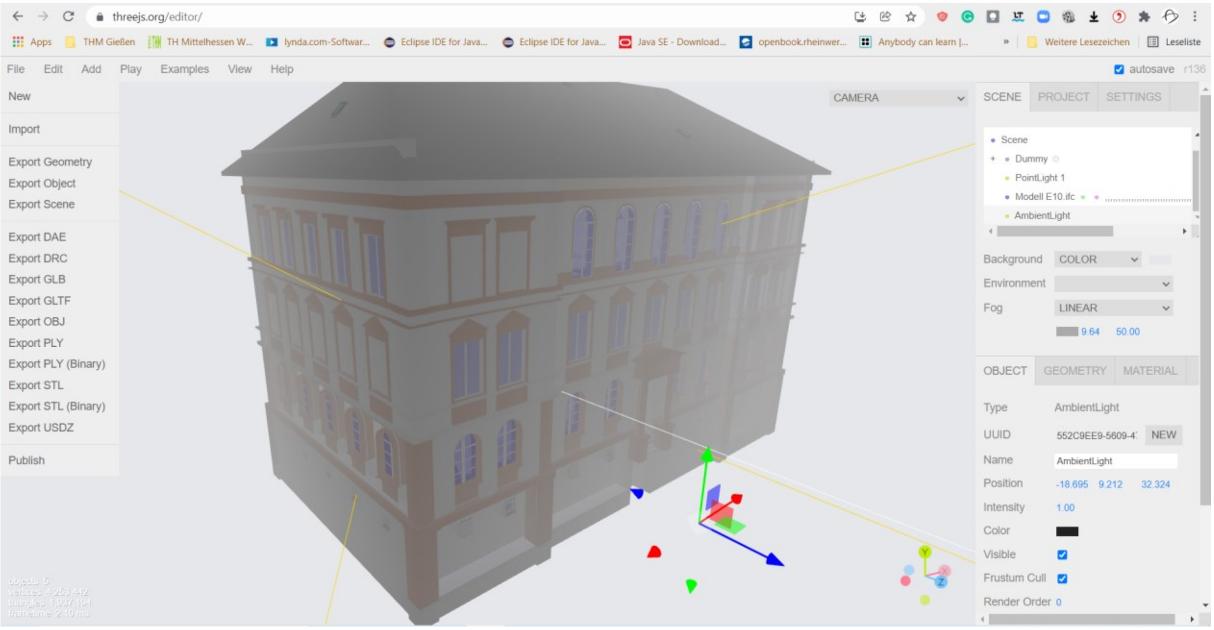


Figure 29: Test of IFC Model in Editor threejs.org/editor/ (Quelle: A. Juraboev)

3.4.3 Data Service System Architecture

A web application framework is a collection of software that supports the development of web-based services. The *openNaviBIM* application is web-based and is used in both, web platforms and apps. The system architecture for the *openNaviBIM* multi-platform application is shown for the Meteor Framework [105] from a bird's eye view as follows (see *Figure 30*).

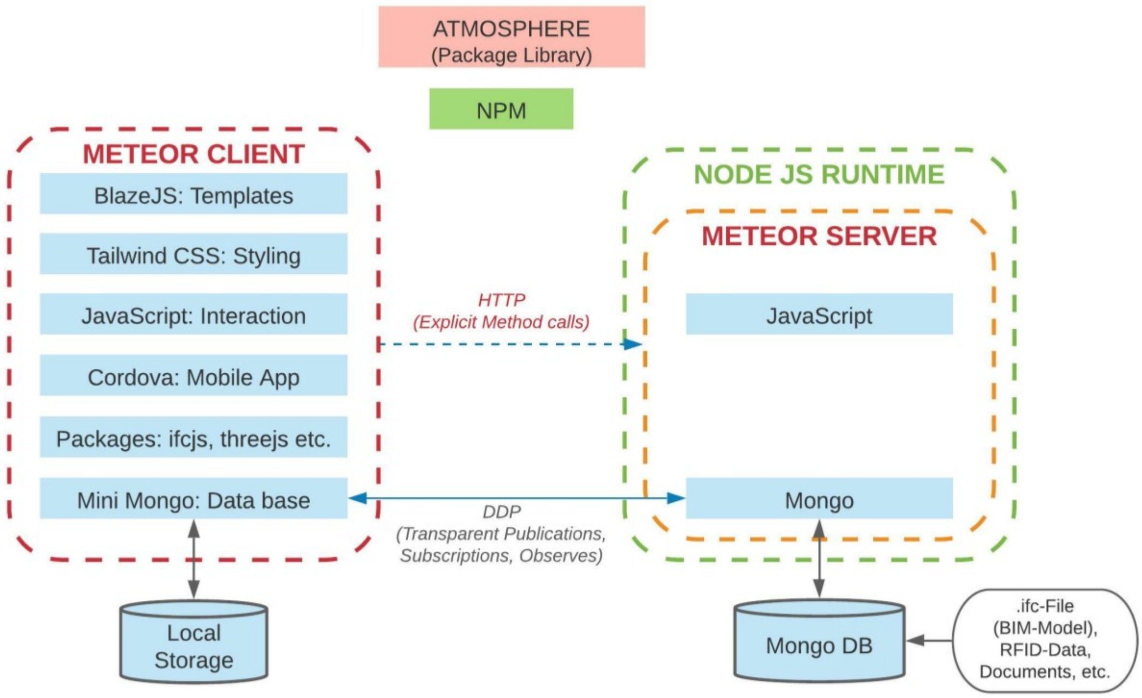


Figure 30: Data Service System Architecture of openNaviBIM Cross-Platform-Application (Source: A. Juraboev)

3.4.4 Used Soft- and Hardware Components

The software and hardware components used in the development of the prototype are listed in *Table 6*:

Table 6: Used Soft- and Hardware components

Nr.	Item	Tools	Purpose	Interface	Version
		Software Components			
1.	BIM-Model	Revit (Autodesk BIM authoring tool)	Modelling	.ifc	2021
2.	Integrated Development Environment	Visual Studio Code	Source Code Editor		1.63.2
3.	Software-Framework Backend	Meteor	Cross-Platform Code		2.5, 2021-10-21
4.	Cross-platform Backend	Node.js	JavaScript Runtime Environment		14.16.0
5.	Software-Framework Backend	Apache Cordova	Mobile Application Development Framework		

6.	RFID Demo Software Reader	"ReaderControlUHF" by metraTec	RFID "ID" Mid-Range Reader	.xls	1.10.00
7.	Application Server	Heroku Cloud	To deploy Web-application		
8.	File Server	Digital Ocean	To deploy IFC-Files		
			Hardware Components		
9.	Hardware RFID-Reader	Bluetooth-Long-Range UHF-RFID-Reader (868 MHz) ISO18000-6	RFID-Reader	BLE 2.0	URA BLUE
10.	Hardware RFID-Reader	Prototype RFID-Antenna ARRN5	RFID-Reader	BLE 4.2	

3.5 The Proof of Concept

The selected software applications are freely available as an open source for proof of concept and can be freely installed in any platform, such as Microsoft Windows or Mac PC operating systems (*Figure 31*). First, a complete digital building model was exported into the open source .ifc format. Then the database system (MongoDB) and a JavaScript server (MeteorJS) were set up as a "backend". IFC.js and Three.js, the open-source JavaScript libraries, were used to load, display and edit the IFC models in a browser or an app. With the help of IFC.js the IFC models, including all their information, can be visualised in common browsers and mobile devices.

Connecting the RFID reader to the *openNaviBIM* app on a smartphone, using the NFC tag, works well. After reading the NFC tag using an Android smartphone, the marked element in the BIM model is highlighted in the app, and the audio message, which is stored in the BIM model, is played.

The use of an RFID reader will work in a similar way. Here, the RFID tags are scanned using an RFID reader, and the reader is linked via the *openNaviBIM* app using Bluetooth.

At the THM Giessen Campus, RFID tags are already installed in the test site.Therefore, these can readily be used, for example, for the development of the first BIM-supported navigation and positioning system using the *openNaviBIM* app via Bluetooth.

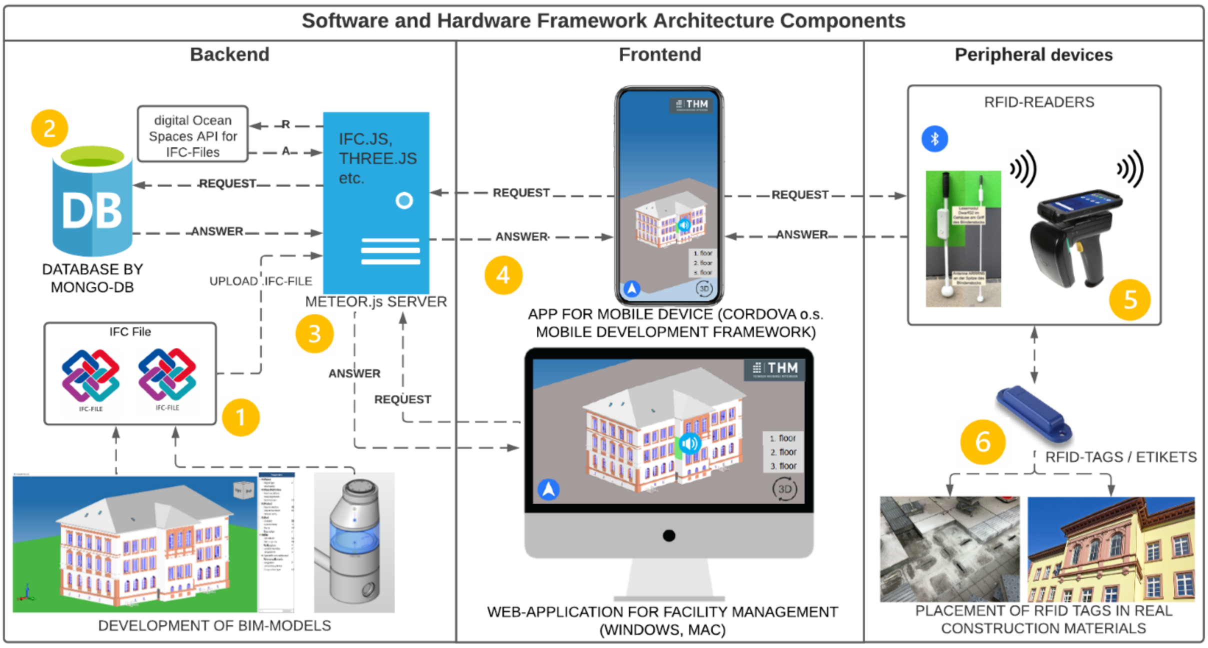


Figure 31: The Architecture of RFID and Wireless IoT Technologies in BIM to develop Cross-Platform-Application (Source: A. Juraboev)

(1) Modelling and attributing the BIM model, and providing it in a standard IFC file (STEP 21 format).

(2) In database MongoDB, the IFC-Model is accessed and checked using the written IFC instance file, code and provided for users.

(3) Using NodeJS and Cordova, the MeteorJS web framework enables the cross-platform code to work in the Web-application. Digital Ocean Spaces API used for IFC files.

(4) Developing a multi-platform open-source application (smartphone app for users, web application for administration, e.g. facility management).

- ifc.js, three.js Javascript packages for 3D model rendering, visualisation, etc.
- Apache Cordova open-source mobile app development framework

(5) RFID, Arduino, PDA readers, which can be accomplished in different forms, depending on their application.

- RFID reader and mobile app connection via Bluetooth (at least BLE 4.0)
- Development of trigger function for RFID technology

(6) Integrating the RFID tag/attachment/label into building and construction materials during the production and operation phases.

4 PRACTICAL PART

4.1 Overview

Various mechanical/electrical elements, such as sensors, have already been integrated into the current version of the IFC standard by defining entities or types. However, RFID elements are not yet defined in the current edition of the IFC standard,[106]. Therefore, in the practical part of this work, RFID elements were initially defined in the context of prototype development. This was done by using proxy elements *(IfcBuildingElementProxy)* and property sets or types in BIM models. In one study, [107], it was proposed to integrate the components of the RFID system into the IFC standard, either by mapping them to existing IFC definitions or by defining new entities. However, the integration of new entities or types (e.g. a physical object) into the IFC standard usually takes several years.

The integration of RFID components and physical building elements into digital BIM models offers practical advantages for various applications. Possible areas of application are the integration of RFID tags, e.g. for the development of electronic guidance systems to be used for the orientation of mobility-restricted people, or their integration into infrastructure objects for their location, and BIM-supported documentation and maintenance of structures in facility management. The connection of physical and virtual components, to develop a digital twin for different services, using innovative technologies and methods is summarised in *Table 7*.

Table 7: Items of the related components for the implementation of the digital twin

Nr.	Item	Components
1	Physical part	Structure, components, building materials and elements, built environment (physical buildings and infrastructure)
2	Virtual part	BIM object, BIM model and BIM data in openBIM (IFC format)
3	Connectivity for coupling (connecting of the components)	RFID tags /label, RFID reader or PDA, mobile devices, WLAN/Wi-Fi, BLE Bluetooth
4	Methods of data providing	Implementation and programming for coupling the software and hardware components, e.g. RFID data, BIM data
5	Services	Navigation system, tracking system, information management in facility management

4.2 PART I: Creation of the BIM Model and Integration of RFID Tags in the BIM Model

4.2.1 BIM Modelling Guidelines

The BIM Modelling Guideline defines the model creation, as well as the structure and requirements for the models and their structural components. For the planning and design of the BIM model, the Revit version 2021 software was used. Revit, by Autodesk, is one of the most widely used BIM-supported software [108]. The basis for the planning and modelling of BIM models was the import of CAD and image files into Revit Autodesk Revit has and supports various standards and data formats for importing and exporting data.

- Revit-own formats: RVT, RFA, RTE, RFT
- CAD formats: DNG, DWF, DWG, DXF, IFC, SAT, SAK
- Image formats: BMP, PNG, JPG, JPEG, TIF
- Other formats: ODBC, HTML, BCF, TXT, gbXML, and Point Clouds (RCS, RCP) [109].

In the practical part of this work, the focus was not on the individual modelling steps in Revit, but on the creation of the loadable BIM objects, BIM projects and the integration of RFID tags into BIM models. The building elements that are not defined in the BIM modelling tools were developed as a building element family (BIM objects or also called Revit Content). This way, they can be imported and used in any project. As an example, in this work, the following loadable component families (BIM objects) were modelled as RFA files for the "Proof of Concept":

1) Modular, textile floor coverings in various sizes in the form of knobs, strips and standard elements for indoor spaces (see *Figure 32*).
2) Components of sewer manhole systems (shaft) in urban water management (*Figure 33*).
3) Different sized RFID tags as an element (see *Figure 36)*.

According to the Open BIM principle, these loadable component families, with defined parameters and attributes, can be used (imported or loaded) with minimal effort in any project with Base or Survey coordinates via an IFC interface available in Revit.

4.2.2 Creation and Classification of Loadable Component Families in Revit

1) Creation of Parametric Modular Textile Floor Coverings as a BIM Object

The objectives were the parametric modelling and attribution of textile modular floor coverings of the company “TFI-Instituts für Bodensysteme an der RWTH Aachen e.V.” as BIM objects in different sizes. The existing TFI Institute’s design concept was used to model the textile flooring (*Figure 32*) in BIM-based software with different patterns (e.g. tufted structure: stripes, knobs) using LOD 300. The geometry of the loadable component family is 500 mm x 500 mm and was provided with parameters such as dimensions, material, manufacturer data.

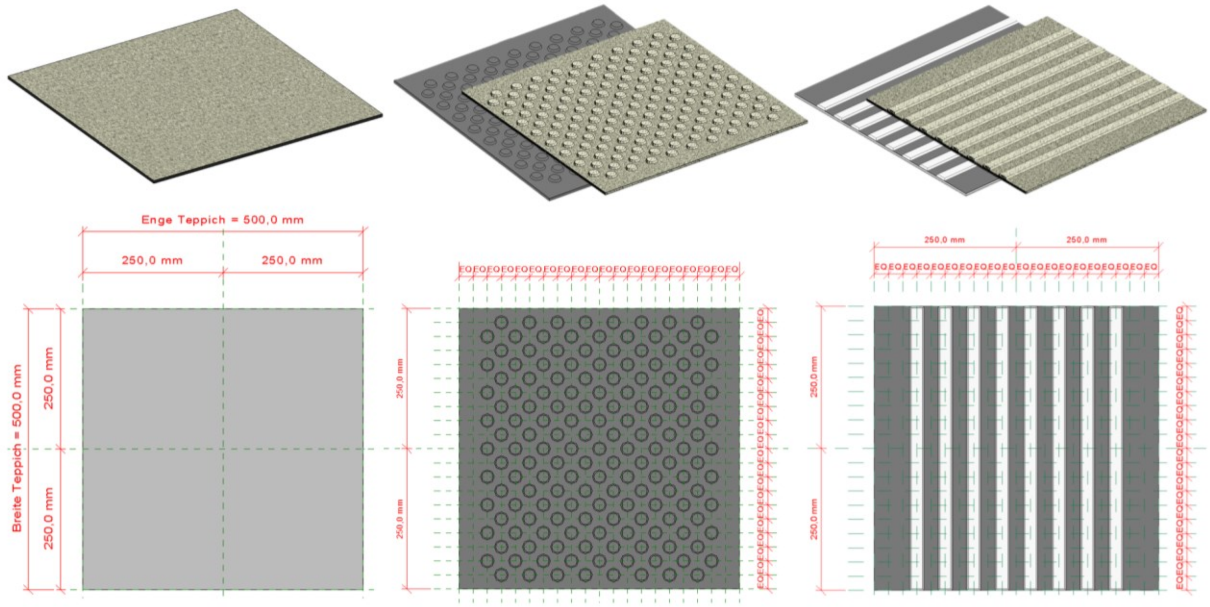


Figure 32: Modelling of a loadable BIM object for textile flooring with knobs and stripes (Source: A. Juraboev)

The surface structure of the textile floor indicators for indoor spaces was modelled according to the German standard DIN 32984: 2020-12 - Floor indicators in public areas [110], (middle: knob structure and right: rib structure).

2) Creation of Parametric Concrete Inspection Chambers as a BIM Object

The objective was to model components of a parametric inspection chamber (*Figure 33*) that can flexibly assume different dimensions and complies with the German Standards (DIN EN 1917 and DIN V 4034-1), [111]. As a template for this, the technical data sheets of the DIN maintenance hole systems of the company "Finger Beton GmbH" [112] were used.

According to the above mentioned Standards, an inspection chamber usually consists of the following components:

- Manhole cover
- Manhole grade ring (AR-V)
- Manhole taper top (SH-M)
- Manhole ring (SR-M)
- Manhole base (SU-M)

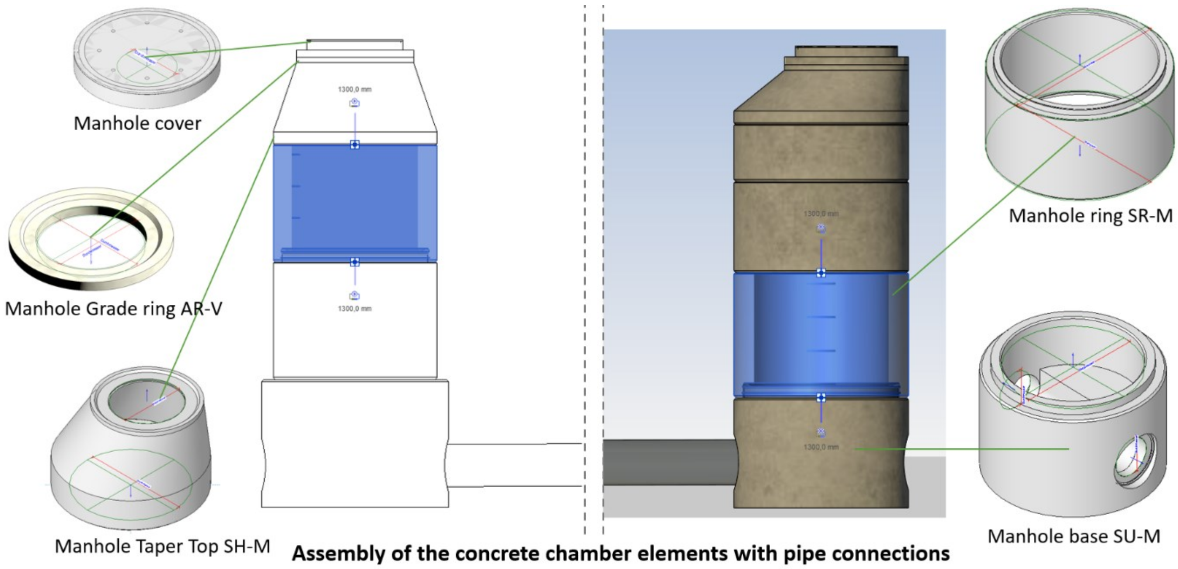


Figure 33: Modelling of loadable BIM objects for a manhole chamber (Source: A. Juraboev, N. Oerter, E. Bagherifard)

The approach was to model all the single parts as a separate Revit component family using the detail levels 100 to 300, then to attribute and load them into a Revit project (*Figure 34*).

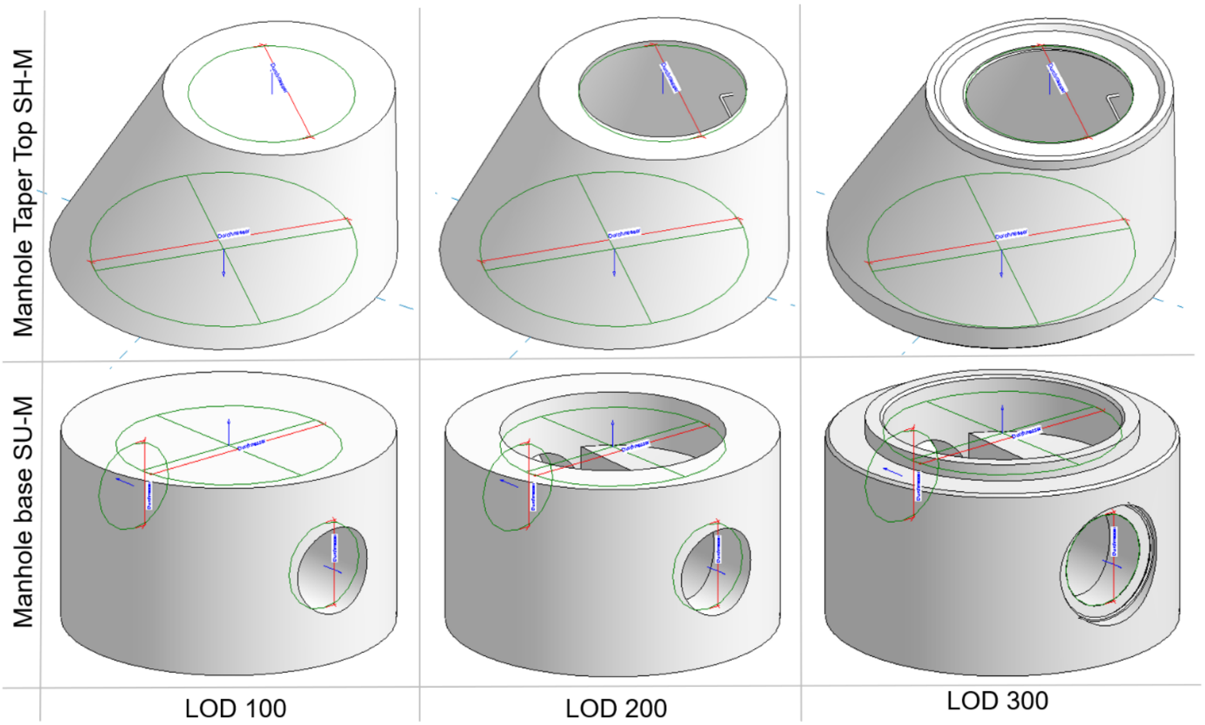


Figure 34: Visualization of the Levels of Detail (LOD) 100-300 using the example of the SU-M and SH-M manhole components (Source: A. Juraboev, N. Oerter)

Property sets have been added to each maintenance hole component, which the user, according to their needs, can fill in with component information, such as dimensions, manufacturer data, geodata, materials, delivery, storage, etc. (*Figure 35*). In addition, the property sets can be changed manually in Revit at any time.

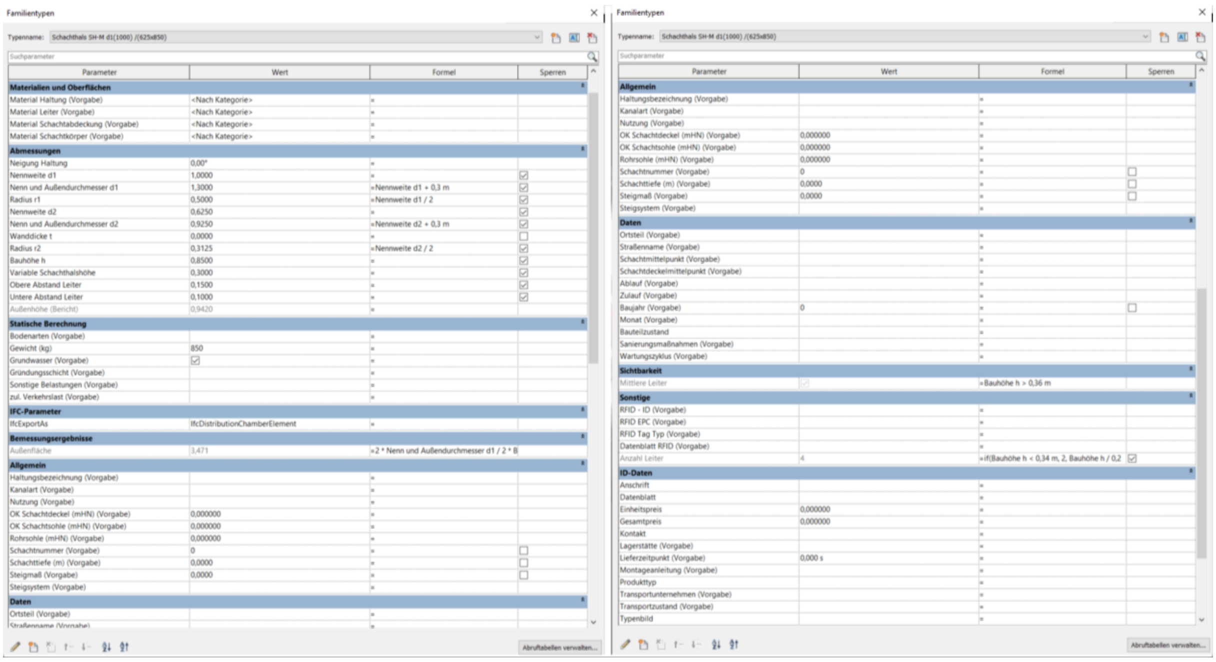


Figure 35: Type and exemplar parameters based on the example of a manhole SH-M element (Source: A. Juraboev)

In addition, the IFC parameter, *"IfcDistributionChamberElement"*, and other important classifications (see *Table 8*) were added to the BIM partial objects. This was done with the help of Autodesk Classification Manager, so that these can be used in any Revit project for the IFC model export.

Table 8: Used classification systems for manhole model

Parameter	**Classification system**
IfcExportAs	IfcDistributionChamberElement
OmniClass-Number	23.70.50.24
OmniClass-Title	Rainwater Removal

3) Creation of RFID Tags as a BIM Object

The objective was to integrate RFID tags as a loadable component family into the digital BIM model. For this purpose, the RFID tags (label, etiquette, inlay) were modelled into and attributed to Autodesk Revit as a loadable component family (*Figure 36*) using various dimensions. The information on the RFID tags modelled in Revit was provided by numerous companies (see *Table 9*). From the RFID manufacturers' data sheets, among other details, the dimensions and the material- and manufacturer-specific data were entered as parameter properties.

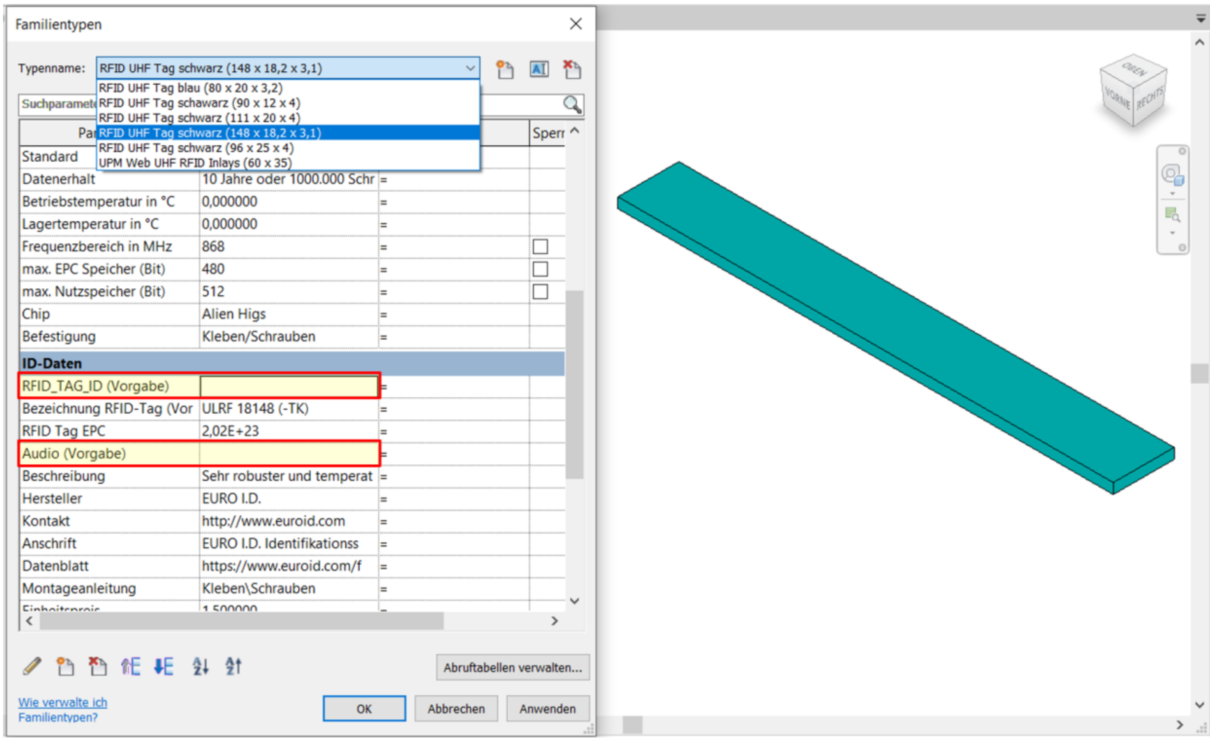


Figure 36: RFID tags as a loadable BIM object with related parameters (Source: A. Juraboev)

During attribution, it is important that the variable family parameters are included as an exemple parameter, since each RFID tag has a unique serial number (ID). This includes, in particular, the parameter data *RFID_TAG_ID* with the data type *“Text"*, as well as the *Audio* with the data type "URL" (see red marked box in *Figure 37*).

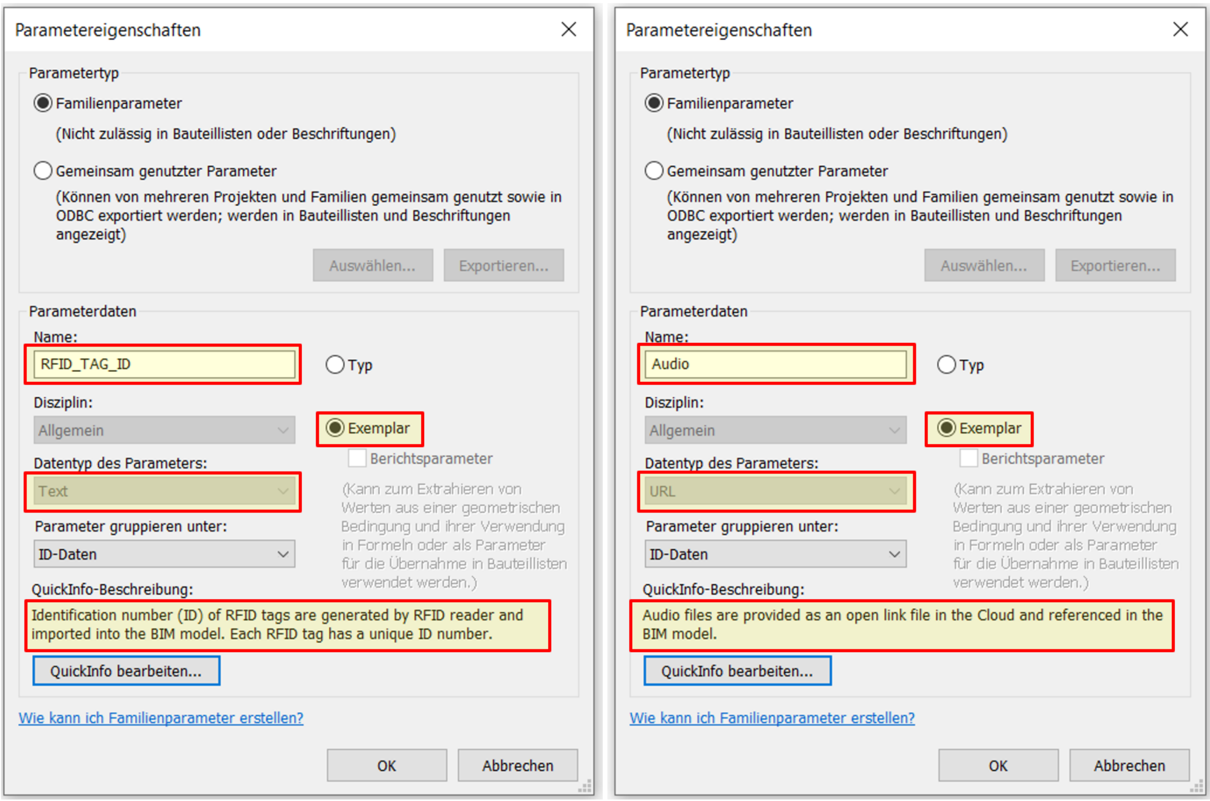


Figure 37: Example family parameters for RFID tags in (.rte) file (Source: A. Juraboev)

RFID tags were specified as generic IFC classes. The BIM objects modelled in this work were classified with the generic and general attribute *"IfcBuildingElementProxy"* for further use. The loadable building element families were saved in the RTE file and can, in future, be modified anytime if required.

4.2.3 Reference Points of BIM Models

At the beginning of any project the basic information (dimensions, units, coordinates) has to be defined, whether in Revit or any other software. In practice, in bigger projects with several parties involved, the basic information and definition of coordinates are clarified at an early stage and described in the Client Information Requirements (CIR) and BIM Execution Planning (BEP).

There are two reference systems:

a) Project origin (Zero Point)

- Internal Origin Point (unmovable)
- Project Base Point (movable)

b) Survey Point / Coordinate (movable)

When working with Revit models, the location for the model origin (= project zero point) is defined. The project origin is described as basically any position in a project that should be as close as possible to the structure and should not change during a project. With regard to Revit modelling, it is recommended that the project base point aligns with the internal origin point and that this position is set as the joint project zero point for the exchange.

The survey point determines the value of the corresponding survey coordinates (*Figure 38*):

4) North/South (=y coordinate)
5) East/West (=x coordinate)
6) Altitude (=Height above sea level)

Using Revit, the method is always the same and the unit is given in metres, regardless of whether UTM or Gauss-Krüger coordinates are applied [113].

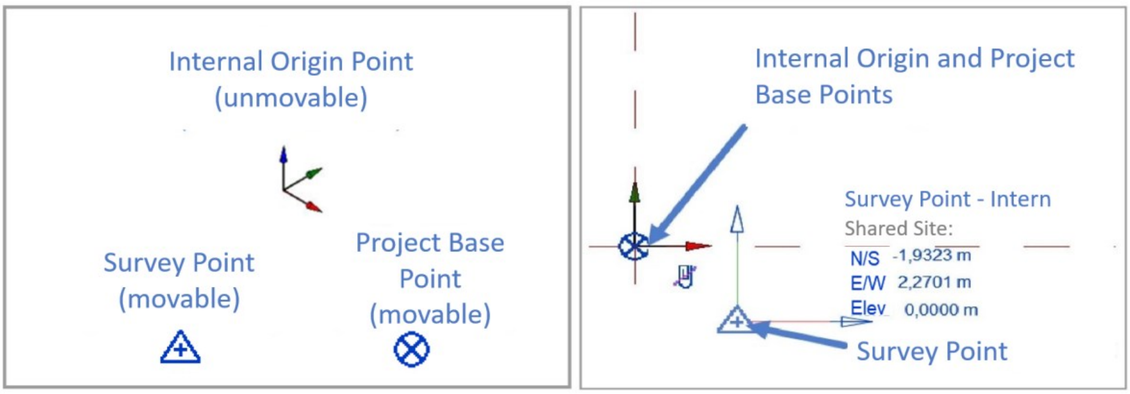


Figure 38: Differentiation of the reference systems in Revit (Example), [113]

In this project, the base points for the coordinates were set during the 'Revit project' (RVT). The data for defining the coordinates were taken from the Geoportal of Hesse. *Figure 39* shows an example taken from the THM, that the coordinates are determined for y (north/south) as 560,3926.7 m and for x (east/west) as 477,458.9 m. The city of Giessen is approximately 159.00 m above sea level (altitude).

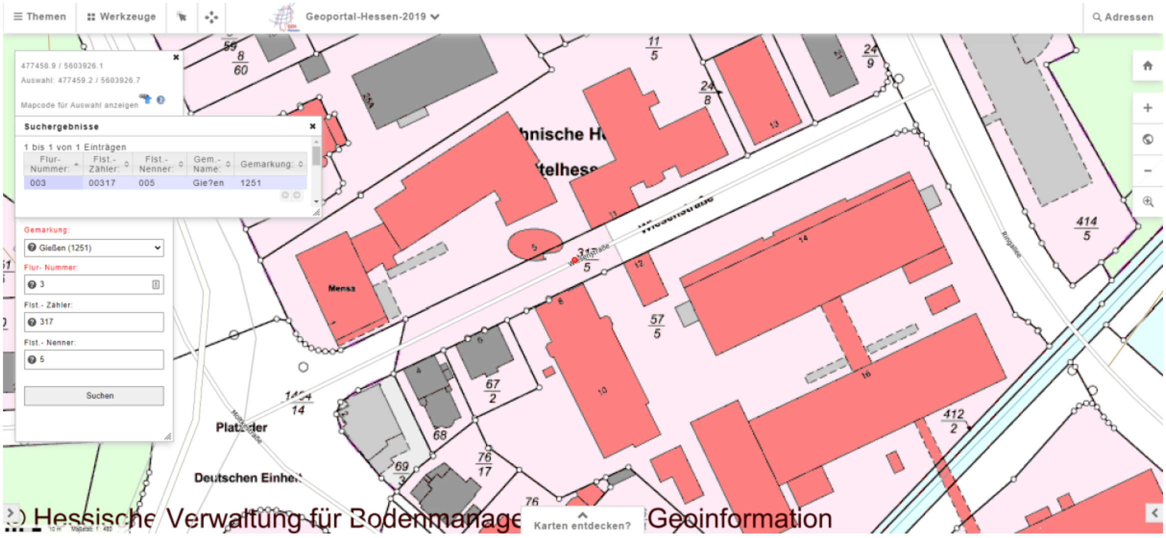


Figure 39: Information for coordinates from the Geoportal of Hessen using the example from the THM Campus A, [114], (Source: A. Juraboev)

4.2.4 Planning of a test field in the BIM project on the example of THM

To begin with, the BIM model of the THM Campus A in Giessen *(see Figure 40)* was modelled in a RVT was visualised with the Autodesk Viewer[5]. In this BIM model a test field was planned, into which the loadable component families (BIM objects) created in *4.2.2* were imported.

Figure 40: Planning of a test field within the BIM project, based on an example of the THM Campus A (Source: A. Juraboev)

[5] Autodesk Viewer is a free online viewer for 2D and 3D designs, including Revit RVT, IFC (STEP 21), AutoCAD DWG, DXF and other files.

The developed loadable BIM objects were equipped with the necessary family and project parameters, which then could be used in BIM model-based data management during the production and service life phases, that is, all data described in loadable Revit component families were assigned or marked in the BIM model (see *Figure 41*).

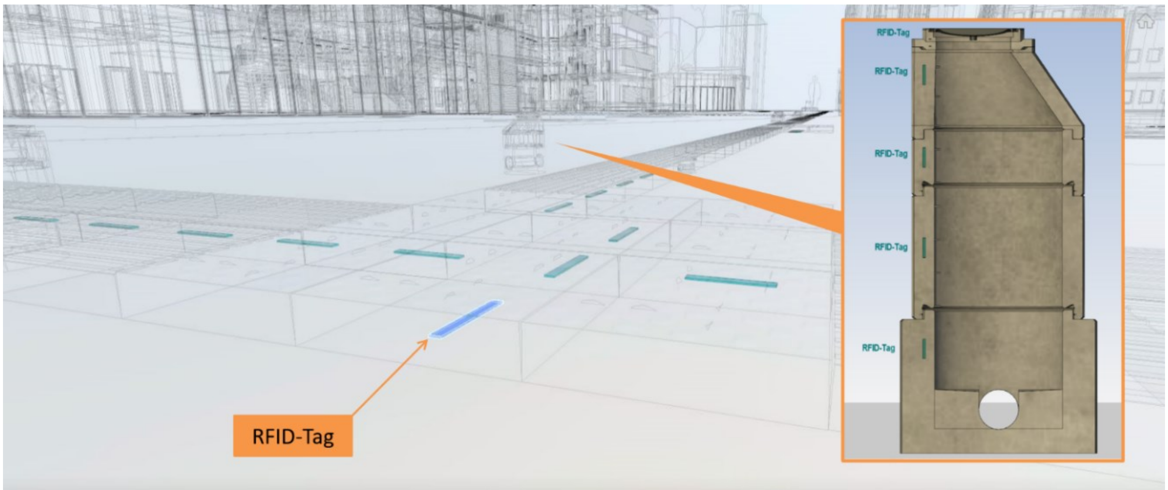
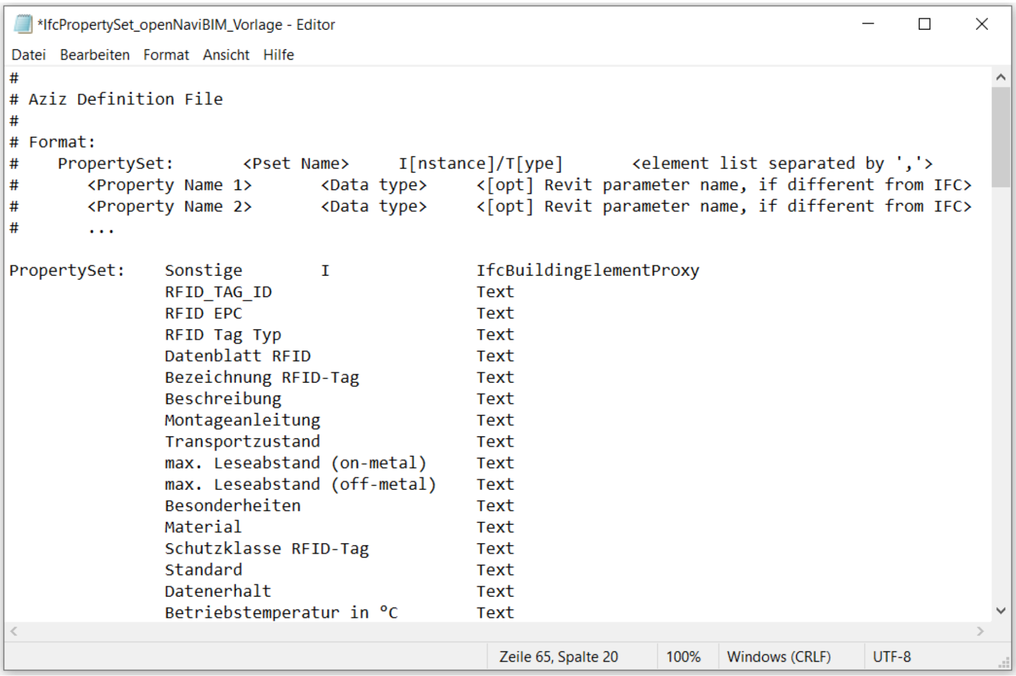


Figure 41: Marking of building elements with loadable "RFID-Tag" items in the Revit project (Source: A. Juraboev)

Most of these parameters were generated in a text file (.txt) as 'exemplar parameters', specifically as a *IfcPropertySet* container (see *Figure 42*), which can, afterwards, be added individually to each BIM project afterwards when exporting text file with *IfcBuildingElementProxy*. "The *IfcPropertySet* defines all dynamically extensible properties. Instances of *IfcPropertySet* are used to assign named sets of individual properties (complex or single properties). Each individual property has a significant name string." [115].



```
*IfcPropertySet_openNaviBIM_Vorlage - Editor
Datei  Bearbeiten  Format  Ansicht  Hilfe
#
# Aziz Definition File
#
# Format:
#    PropertySet:       <Pset Name>     I[nstance]/T[ype]       <element list separated by ','>
#       <Property Name 1>       <Data type>     <[opt] Revit parameter name, if different from IFC>
#       <Property Name 2>       <Data type>     <[opt] Revit parameter name, if different from IFC>
#       ...

PropertySet:    Sonstige        I               IfcBuildingElementProxy
                RFID_TAG_ID                     Text
                RFID EPC                        Text
                RFID Tag Typ                    Text
                Datenblatt RFID                 Text
                Bezeichnung RFID-Tag            Text
                Beschreibung                    Text
                Montageanleitung                Text
                Transportzustand                Text
                max. Leseabstand (on-metal)     Text
                max. Leseabstand (off-metal)    Text
                Besonderheiten                  Text
                Material                        Text
                Schutzklasse RFID-Tag           Text
                Standard                        Text
                Datenerhalt                     Text
                Betriebstemperatur in °C        Text
Zeile 65, Spalte 20    100%    Windows (CRLF)    UTF-8
```

Figure 42: Attribution of the component type properties using a IfcPropertySet (Source: A. Juraboev)

In order to assign the RFID tags to the components (e.g. floor slabs, shafts), an attribute "RFID_ID" with the data type "Text" was created in the project parameters in the Revit project under "ID data" (see *Figure 43*).

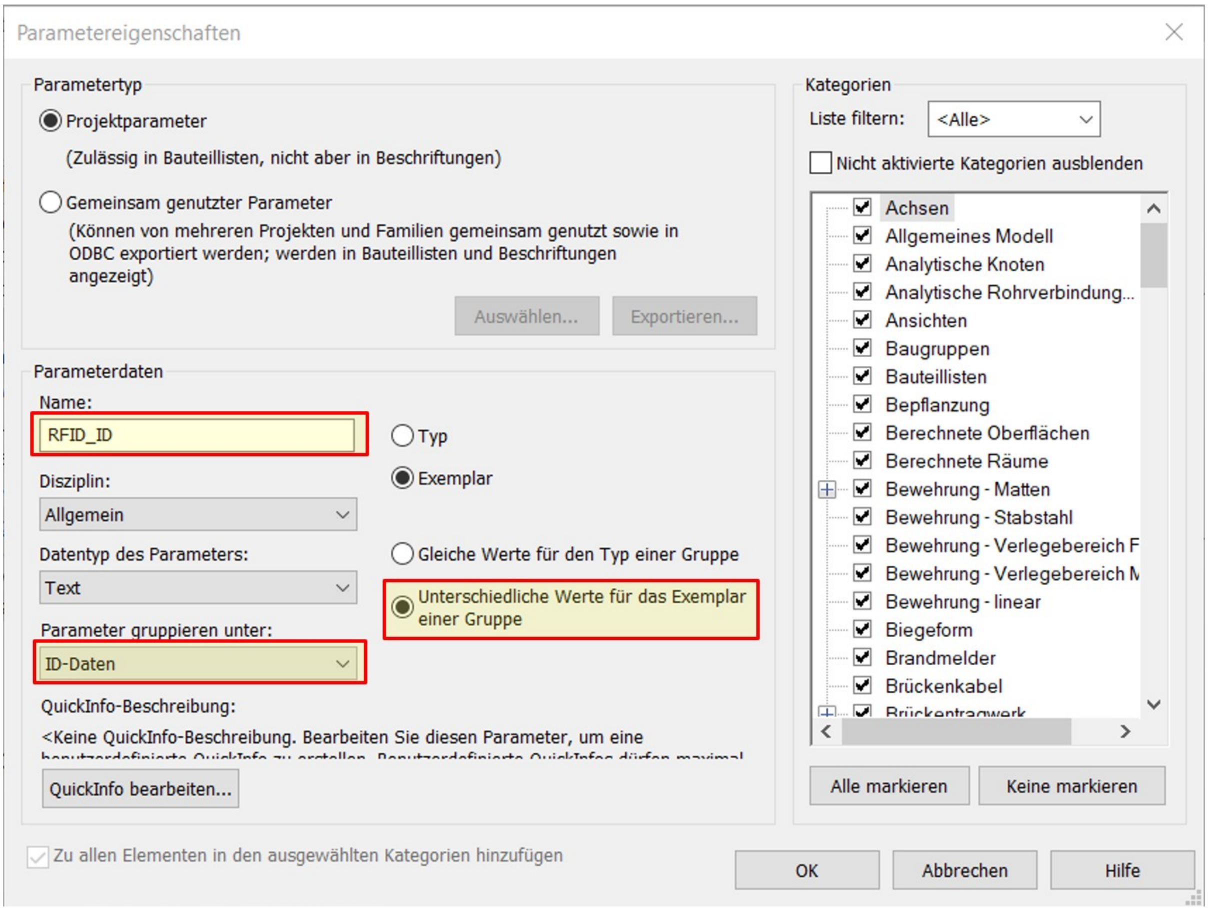


Figure 43: Exemplary project parameters for RFID tags into a (.rvt) file (Source: A. Juraboev)

Initially, the serial number (UID) of the RFID tags, which were read out and documented via an RFID reader, were written as an attribute in Revit project. The procedure for inserting the "UID" of RFID tags in the Revit project is explained in more detail in Chapter *4.2.5* using an example model.

4.2.5 Integration of RFID Tags into the BIM Model

After the created loadable component families, precisely BIM objects in the Revit project, were loaded (imported) and aligned with the digital building models, the RFID tags were linked to the digital building models via serial numbers in the property parameters (family and project parameters). The method for integrating and linking RFID tags into/to the BIM model was defined in *Chapter 1.1* when referring to the problems of the t use scenarios.

Scenario 1: Assignment of several RFID tags to one building element (or structure)

In practice, several RFID tags can be inserted into and assigned to a building object (e.g. a floor slab made of screed, a textile floor covering or large-area floor tiles), (see *Figure 44*).

When inserting, the tags will have a certain distance, depending on the RFID type property, apart.

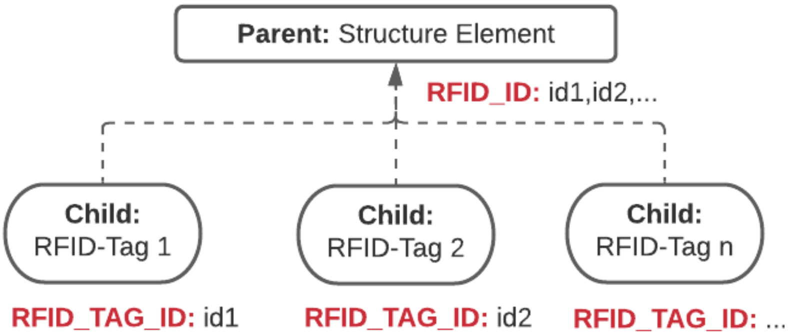


Figure 44: Assignment of several RFID tags to a single structural element (Source: A. Juraboev)

In scenario 1 two RFID tags (child) in a floor covering (parent) were modelled in the Revit project. In *Figure 45* the "UID" serial numbers of the respective RFID tags are labelled "id1" and "id2" under the RFID_TAG_ID (family parameter). Then the "UIDs" of the respective RFID tags (see *Figure 46*) were entered under the RFID_ID (project parameter), with "id1,id2" in the floor covering entered without spaces and with fractional digits.

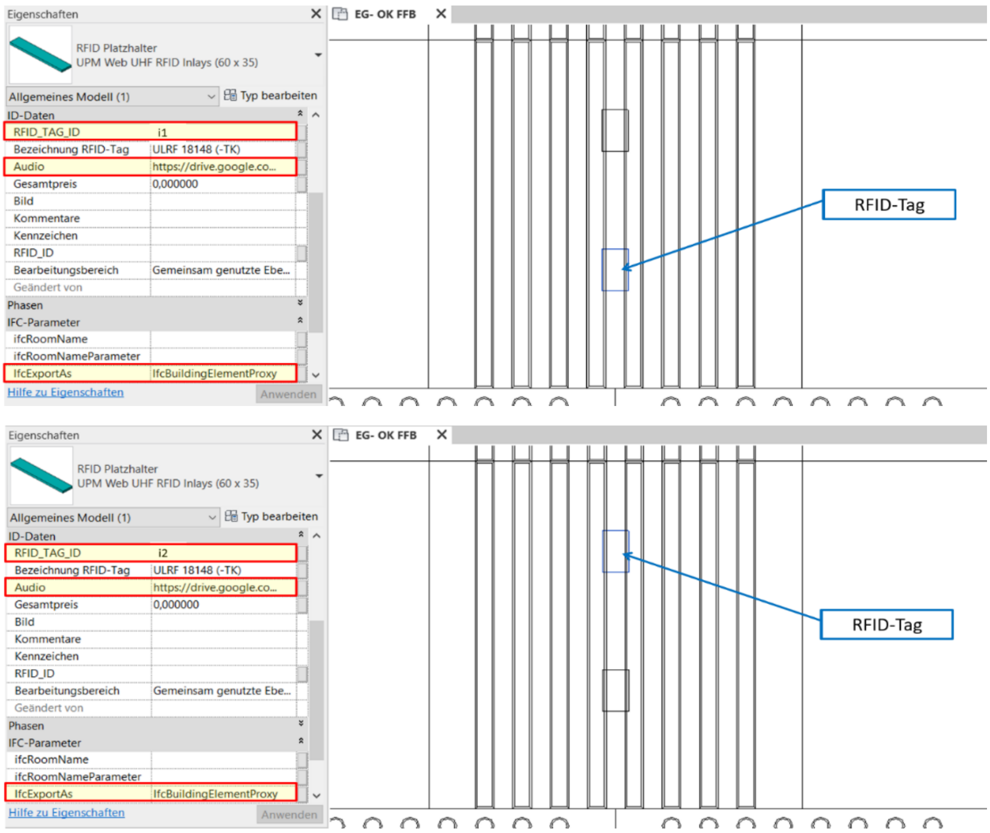


Figure 45: Attribution of "RFID_Tag_ID" and "Audio" of the child element (Source: A. Juraboev)

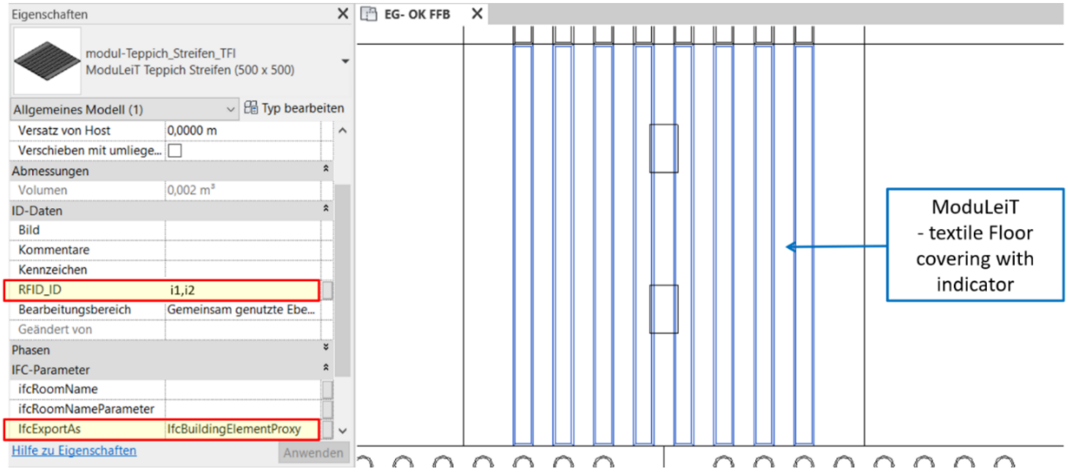


Figure 46: Attribution of "RFID_ID" of the parent element (Source: A. Juraboev)

Scenario 2: Assignment of an RFID tag to a building object (or structure)

In scenario 2, one RFID tag was assigned to one component element (Figure 48), i.e. one parent element has only one child element.

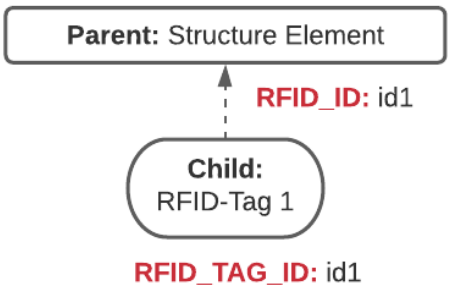


Figure 47: Assignment of one RFID tag to a single structural element (Source: A. Juraboev

The serial number of the RFID tag was entered in *Figure 48* under RFID_TAG_ID (family parameter) with "id1".

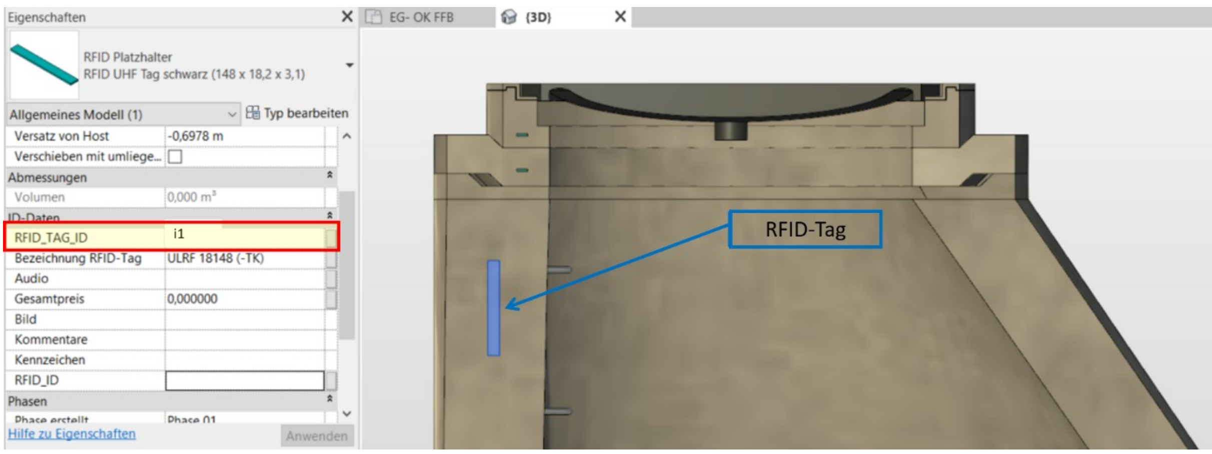


Figure 48: Attribution of the RFID_TAG_ID of child element (Source: A. Juraboev)

Subsequently, the "UID" of the RFID tag was specified as "id1" under the RFID_ID (project parameters) (see *Figure 49*).

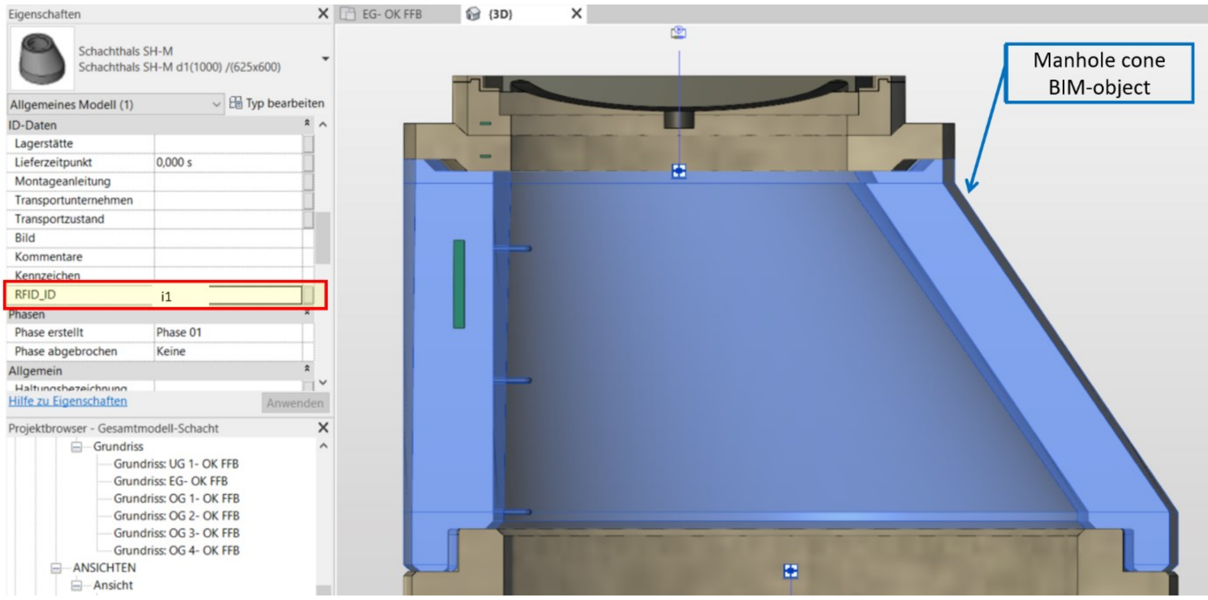


Figure 49: Attribution of "RFID_ID" of the parent element (Source: A. Juraboev)

4.2.6 Exporting the IFC Model in Autodesk Revit Software

The developed BIM model, including the integration of RFID tags into the BIM, was exported in IFC format for further use. Here the smooth flow of information, the complete semantic and geometric data, is important, for example to display BIM model parameters in the *openNaviBIM* platform. In this project, after numerous tests, *IFC 2x3 Coordination View 2.0* was used, as this version enabled a qualitative visualisation of the BIM models without data loss. For the Export, any coordinate base of the digital building can be used (see *Figure 50*).

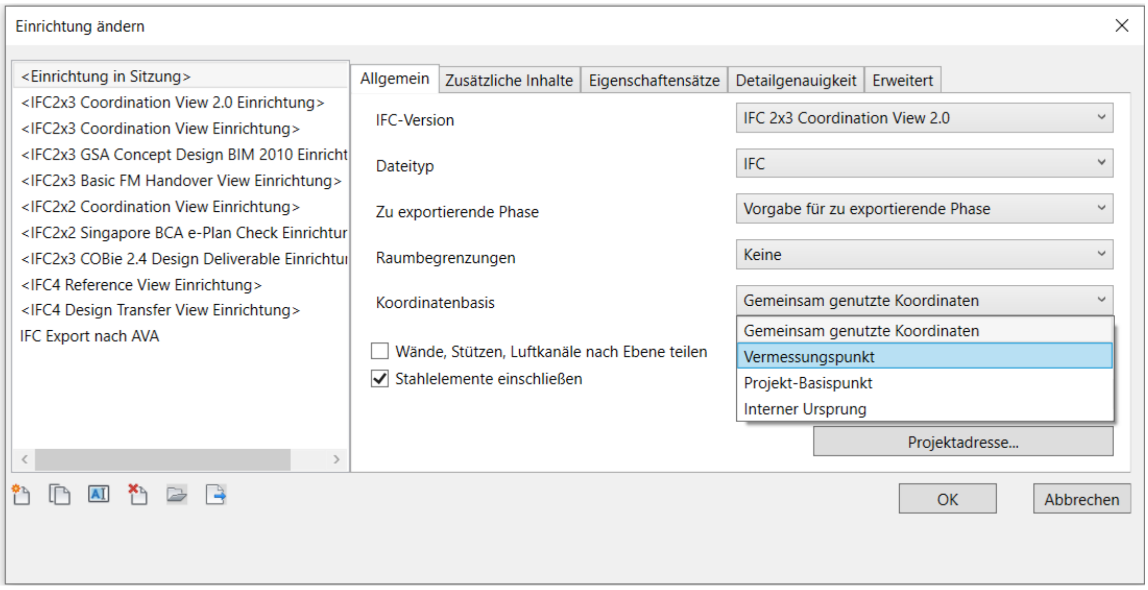


Figure 50: General information on exporting the Revit project (Source: A. Juraboev)

In order for the IFC model to contain all relevant parameter properties, certain items must be set into property sets (*Figure 51*). In this case, the parameter assignment table from *Figure 42* has been exported (see *Appendix A*).

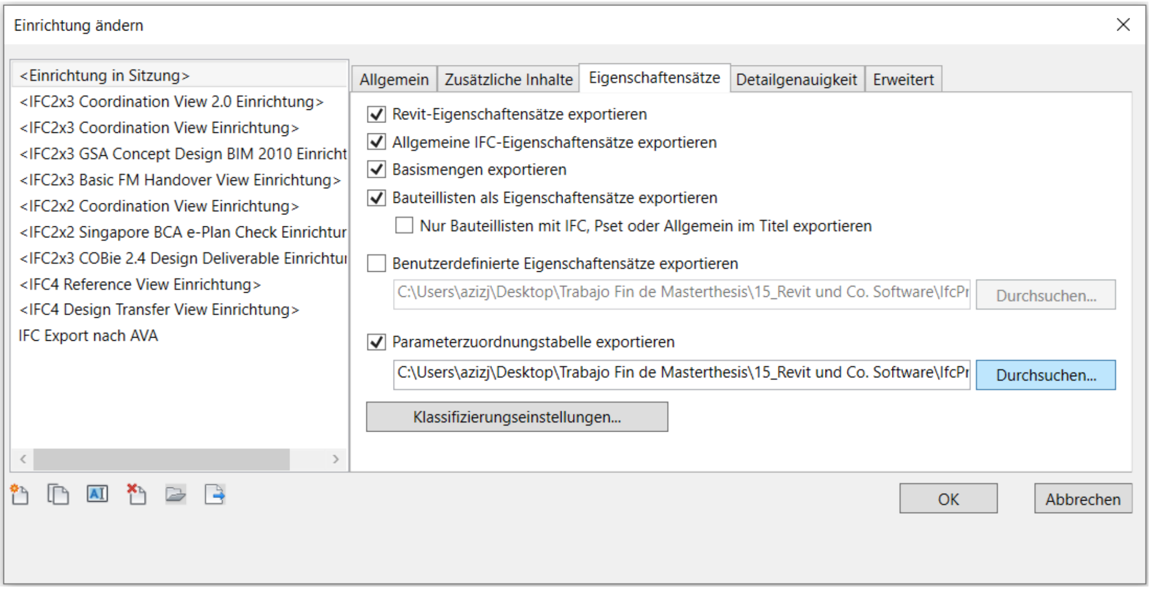


Figure 51: Property sets for exporting the Revit project (Source: A. Juraboev)

For the IFC model, the building elements' level of detail (LOD) can be specified according to the requirements and data size (see *Figure 52*).

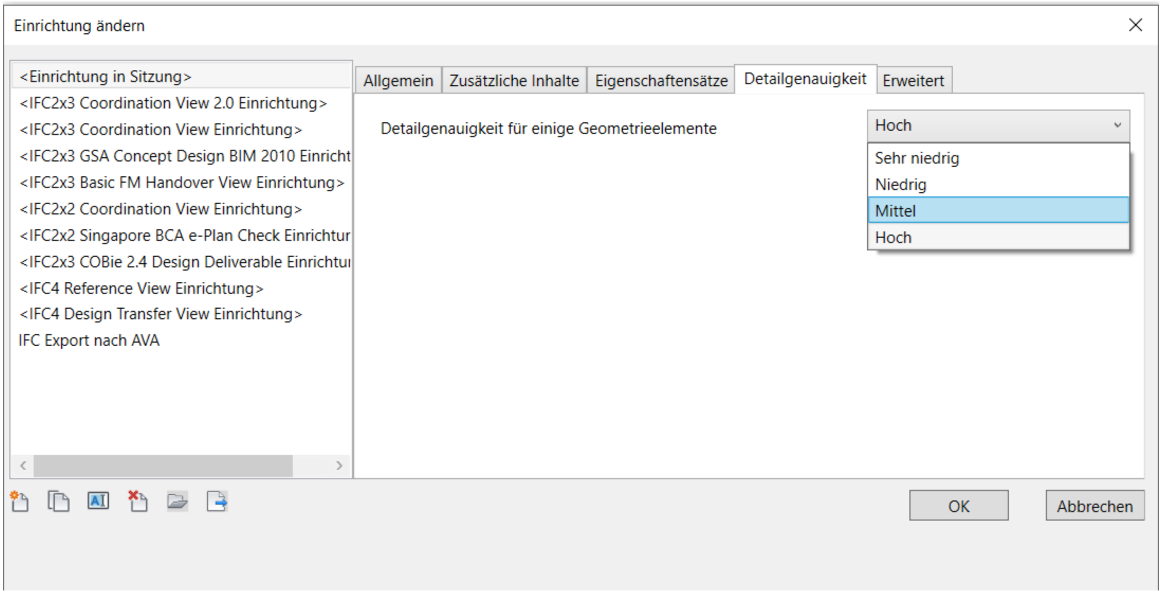


Figure 52: Geometric detail for exporting the Revit project (Source: A. Juraboev)

After successful modelling and exporting to an IFC file, the IFC models were uploaded to the developed *openNaviBIM* web application via a browser and provided to the end users.

For the following reason the IFC4 is not yet recommended: As *IFC4 Reference View* and *IFC4 Design Transfer View* are still under development, some parts of the BIM model were not fully viewed during testing in the BIM viewer. Furthermore, *IFC2x3 Coordination View 2.0* was used in this project. "The opening (importing) of an *IFC4 Reference View* in a BIM editor, like Revit or the usage for other applications, such as simulation and analysis, does not lead to optimal results." [8]. Therefore, *IFC 2x3 Coordination View 2.0* is recommended for the use in *openNaviBIM* until *IFC4 Design Transfer View* and the other MVDs, specifically designed for IFC4, are available.

4.3 PART II: Integration of RFID Tags into Building Materials

4.3.1 Overview

The objective was to identify the on the market available RFID tags for integration into different building materials (e.g. textile, mineral and plastic floor coverings, concrete components) and to integrate the selected suitable ones into the building objects on the basis of the laboratory test results. Taking these into account, the selection of the RFID tags, according to the installation situation and the building materials' receiving range, were examined in detail.

4.3.2 Used RFID Components

First, information on RFID manufacturers and suppliers of passive RFID systems in Germany was researched and numerous companies were contacted. The following companies provided RFID tags (inlay or label), as well as RFID readers for the test experiments (see *Table 9*).

Table 9: List of RFID manufacturers and suppliers (Source: A. Juraboev, Louisa M. Zobel)

Nr.	**Companies**		
	Name (GmbH, AG etc.)	Homepage	Components
1	ARFIDEX GmbH	https://www.arfidex.de/	RFID tags, RFID reader
2	smart-TEC GmbH & Co. KG	https://www.smart-tec.com/de	RFID tags
3	Dynamic Systems GmbH	https://www.dynamic-systems	RFID tags
4	EURO I.D. Identifikationssysteme GmbH & Co.KG	https://www.euroid.com/	RFID tags
5	F.H. Papenmeier GmbH & Co.KG	https://www.papenmeier.de/de/	RFID integrated blind cane

a) Passive RFID Tags

For the laboratory tests, ultra-high-frequency (UHF) RFID tags were selected, because, according to the results of one research report [25], they are suitable for integration in different building materials based on the following criteria:

- RFID tag robustness
- Water resistance (protection from water)
- Protection from foreign objects
- Thickness of RFID tag

The investigated UHF RFID tags with their dimensions are shown in *Figure 53*.

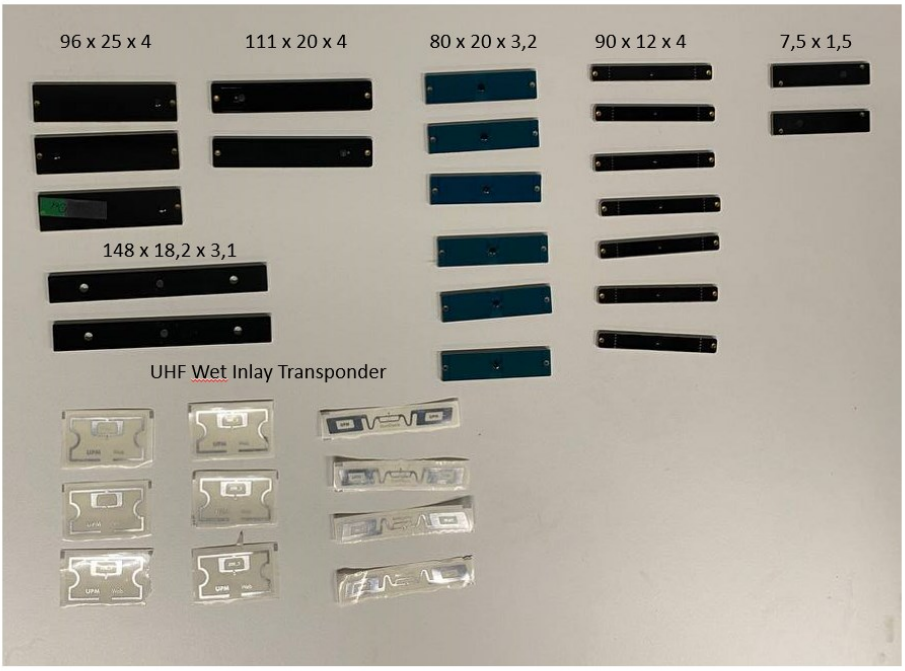


Figure 53: Tested UHF RFID tags with specification of dimensions (Source: A. Juraboev)

b) RFID Reader

The following RFID readers were used to investigate the receiving range of RFID tags embedded in the building materials:

- 3D-printed, RFID Reader integrated cane by Papenmeier company (see *Figure 54*).

The electronic 3D-printed cane for the blind contains an RFID antenna (ARRRN5, 4x4 cm) at the head of the cane and a compact RFID reader (SMD module, DwarfG2), supplied by metraTec, in the box on the handle. The cane is able to read the UHF RFID tags.

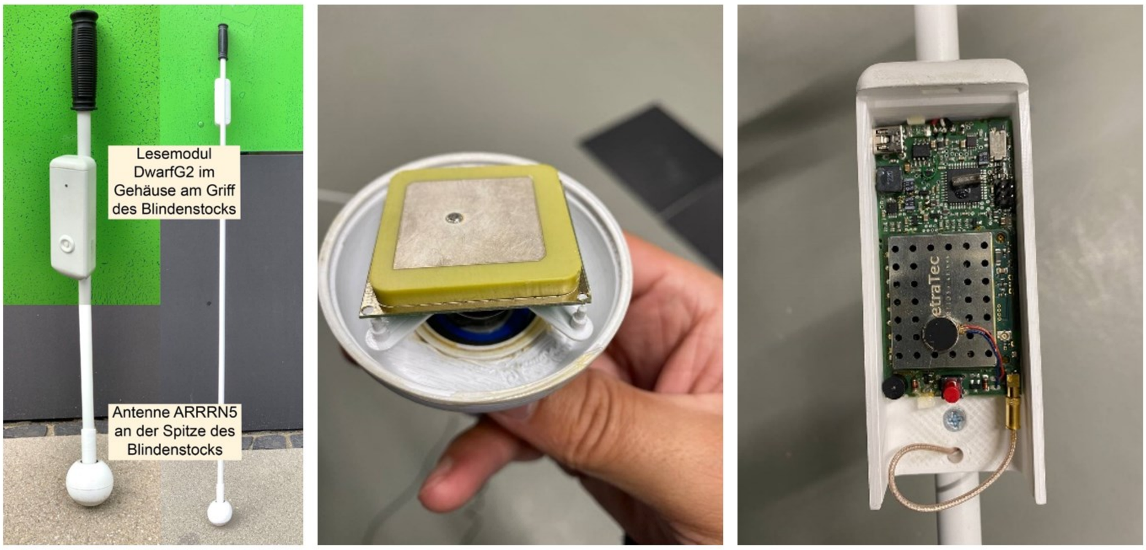


Figure 54: 3D-printed blind cane with integrated RFID reader and antenna (Source: A. Juraboev)

- URA BLUE UHF RFID reader from supplied by Arfidex

The URA BLUE RFID reader is able to read the RFID tags to detect their range. However, the reader is not suitable for modern mobile smartphones, due to its incompatibility with the Bluetooth 2.0 version. Similar RFID readers with current BLE Bluetooth (at least BLE V.4.0) would be well suited for the detection of RFID tags inserted in objects.

Figure 55: RFID reader from the company Arfidex GmbH (Source: A. Juraboev)

For the purpose of documenting the serial number of RFID tags, the metraTec software was used.

4.3.3 Integration of RFID Tags into the Building Materials

The objective of integrating RFID tags into the building materials was to develop an object-based, centimetre-accurate information system. Therefore, the selected RFID tags were integrated into various building materials (in or under the building material) as part of the development of the test route for the "proof of concept".

For the development of an electronic navigation system for the blind, RFID tags of the type ULRF 18148 (-TK) were placed in a test field at the THM Campus. The RFID tags were installed at significant locations (entrances, intersections, junctions) based in attention fields using knobbed plates (points of interest) and in route transponders (WT) using ripple plates in the tactile guidance system (see *Figure 56*). The RFID tags can furthermore be integrated into various building materials, for example in textiles, mineral floor coverings, and in public buildings, such as airports, railway stations, etc.

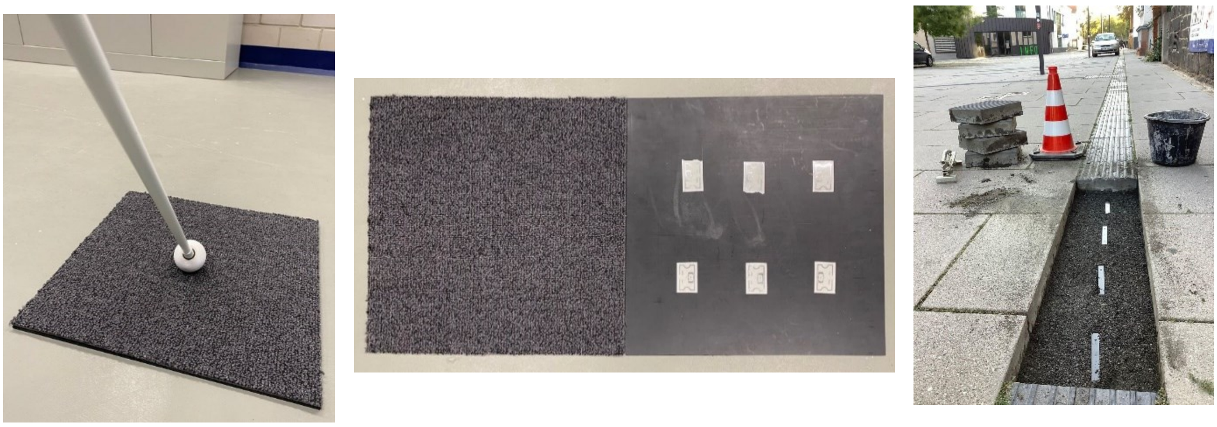


Figure 56: Installation RFID tags under modular carpet (left) and concrete slabs (right) for the development of an electronic blind navigation system (Source: A. Juraboev)

Another field of application is the integration of RFID tags into the maintenance hole systems during the production process. The aim was to, in future, tag (link) the information from shaft elements, that was previously stuck to the shaft elements in paper form (see *Figure 57*) with the serial number of RFID tags.

Figure 57: Manhole elements of the company Finger-Baustoffe GmbH with glued-on manhole information, right (Source: A. Juraboev, M. Bodenbender)

With the integration of RFID tags into the building elements, the asset information is retrieved by scanning the serial number of RFID tags with an RFID reader. BIM-based information, linked by RFID tags in construction objects, is able to support management processes and transport, and can be further used in the operational phase for location and maintenance work.

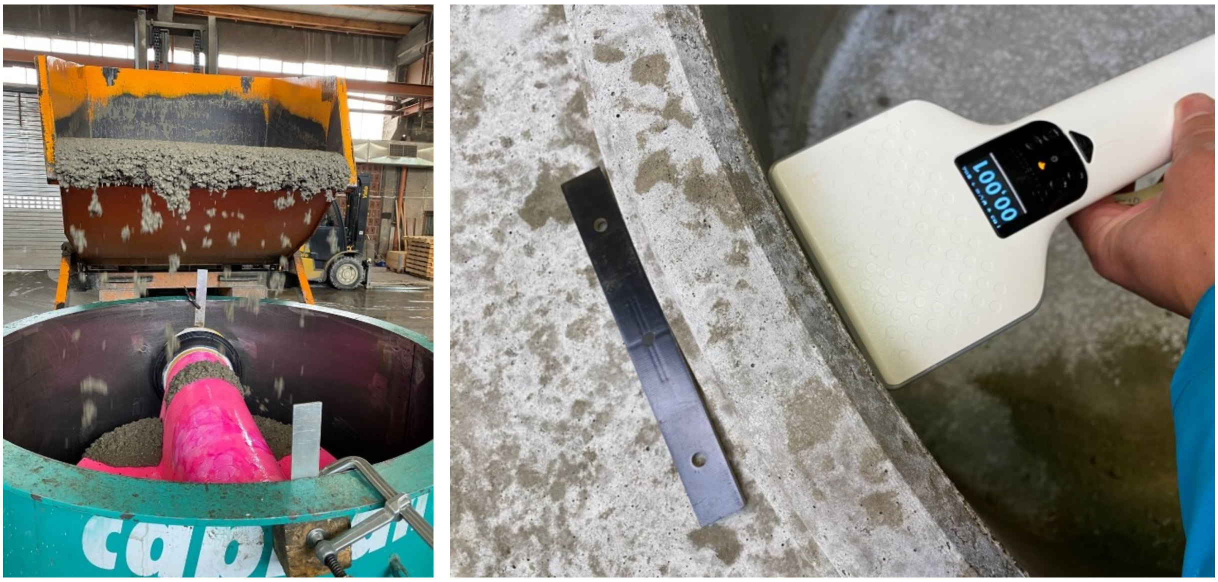


Figure 58: Installation of RFID tags in manhole elements during the production phase (Source: A. Juraboev, M. Bodenbender)

4.3.4 The Experience with RFID Equipments

The experience with RFID equipment's were to read the RFID tags in different installation situations. Depending on these (under, above or in the material), different requirements for RFID tags and reading devices (RFID, PDA (Personal Digital Assistant)) were necessary and accordingly implemented. Further hardware developments are necessary in this field.

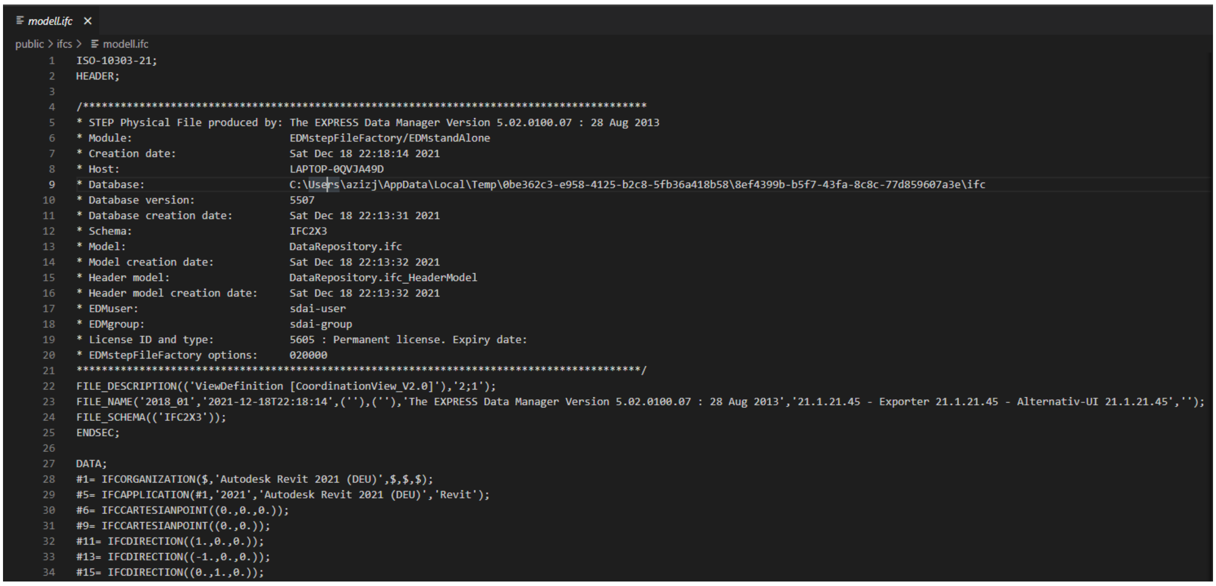
4.4 PART III: Development of Prototype Web-Application

4.4.1 BIM Programming Interface

In Part III, the cross-platform application *openNaviBIM* was developed by using the IFC models already designed in *4.2 Part I.* The development of this web application focused on the processing of BIM modelling data in the manufacturer-independent data exchange format IFC. Ifc.JS. The BIM Toolkit program library for JavaScript was employed for further use and access to the information contained in the IFC instance file was created.

STEP Physical File Format

"IFC follows an object-oriented approach by assigning entities to objects with predefined attributes that can be inherited by all related entities. " [107]. The conceptual schema for IFC is defined using the EXPRESS data specification language (ISO 10303-11), which contains of two parts (see *Figure 59*).



```
modell.ifc
public > ifcs > modell.ifc
ISO-10303-21;
HEADER;

/************************************************************************************
* STEP Physical File produced by: The EXPRESS Data Manager Version 5.02.0100.07 : 28 Aug 2013
* Module:                         EDMstepFileFactory/EDMstandAlone
* Creation date:                  Sat Dec 18 22:18:14 2021
* Host:                           LAPTOP-0QVJA49D
* Database:                       C:\Users\azizj\AppData\Local\Temp\0be362c3-e958-4125-b2c8-5fb36a418b58\8ef4399b-b5f7-43fa-8c8c-77d859607a3e\ifc
* Database version:               5507
* Database creation date:         Sat Dec 18 22:13:31 2021
* Schema:                         IFC2X3
* Model:                          DataRepository.ifc
* Model creation date:            Sat Dec 18 22:13:32 2021
* Header model:                   DataRepository.ifc_HeaderModel
* Header model creation date:     Sat Dec 18 22:13:32 2021
* EDMuser:                        sdai-user
* EDMgroup:                       sdai-group
* License ID and type:            5605 : Permanent license. Expiry date:
* EDMstepFileFactory options:     020000
************************************************************************************/
FILE_DESCRIPTION(('ViewDefinition [CoordinationView_V2.0]'),'2;1');
FILE_NAME('2018_01','2021-12-18T22:18:14',(''),(''),'The EXPRESS Data Manager Version 5.02.0100.07 : 28 Aug 2013','21.1.21.45 - Exporter 21.1.21.45 - Alternativ-UI 21.1.21.45','');
FILE_SCHEMA(('IFC2X3'));
ENDSEC;

DATA;
#1= IFCORGANIZATION($,'Autodesk Revit 2021 (DEU)',$,$,$);
#5= IFCAPPLICATION(#1,'2021','Autodesk Revit 2021 (DEU)','Revit');
#6= IFCCARTESIANPOINT((0.,0.,0.));
#9= IFCCARTESIANPOINT((0.,0.));
#11= IFCDIRECTION((1.,0.,0.));
#13= IFCDIRECTION((-1.,0.,0.));
#15= IFCDIRECTION((0.,1.,0.));
```

Figure 59: The STEP 21 physical file instance (.ifc file) opened in Visual Studio Code (Source: A. Juraboev)

(1) HEADER Section for File Information

The HEADER is a file of the physical file format defined in the alphanumeric STEP standard ISO 10303 Part 21. In the HEADER, the FILE_DESCRIPTION, information on the file name, date of file creation, user, etc., is defined. FILE_NAME and version of the IFC scheme used are specified.

(2) DATA Section for Project Information

These are internal file object identifiers (ExpressId), specified by a natural number preceded by a # sign. In this long list of file-internal identifiers all project information in the IFC standard is defined in layers [3].

4.4.2 UML Use-Case Diagram of openNaviBIM Web-Application

“A use case diagram is one of the diagram types of the Unified Modeling Language (UML), a language for modelling the structures and behaviour of software and other systems. It represents use cases and actors with their respective dependencies and relationships.” [116].

The diagram will not show a lot of detail, but it is a good way to present complex ideas in a basic way.

The use case diagrams are divided into four different elements: Systems, actors, use cases and relationships (see *Figure 60*).

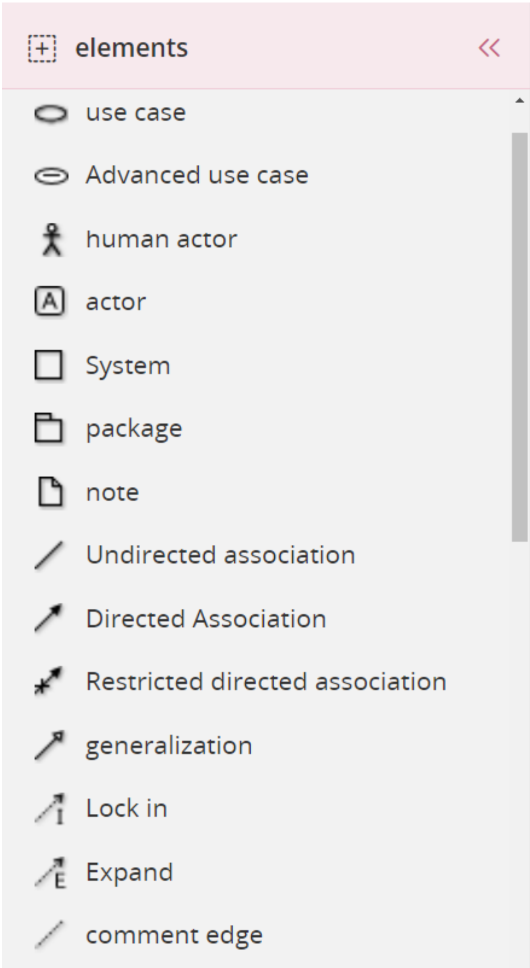


Figure 60: Components of Use-Case Diagram (Source: A. Juraboev)

System: A system is shown in rectangular form and, in this case, defines the *openNaviBIM* web app. Anything within this rectangle happens within the *openNaviBIM* app. Anything outside this rectangle does not happen in the *openNaviBIM* app (see *Figure 61*).

Actor: An actor is going to be someone or something that uses the system to achieve a goal. That could be a person, an organization, another system, or an external device.

For example, the users who download and use the *openNaviBIM* app. Another actor needed in this diagram is the administrator, who will provide information, for example IFC models, that will flow into the *openNaviBIM* app. The actors are external objects. A primary actor initiates the use of the system, while a secondary actor has a more reactive function. For example, the primary actor is a customer. The client will initiate the use of the system by getting out his mobile smartphone, opening the *openNaviBIM* app and doing something with it. The administrator is a secondary actor providing the information the client required using the app.

Use Case: A Use Case represents an action that performs some kind of task within the system. The *openNaviBIM* App will allow an administrator to log into system, load IFC models, check RFID tags, verify UID of RFID tags and confirm the action.

Relationships: A relationship is called an association, and simply means a basic communication or interaction. For example, a customer will interact with the use cases. Besides association, there are three types of relationships; Include, extend and generalisation.

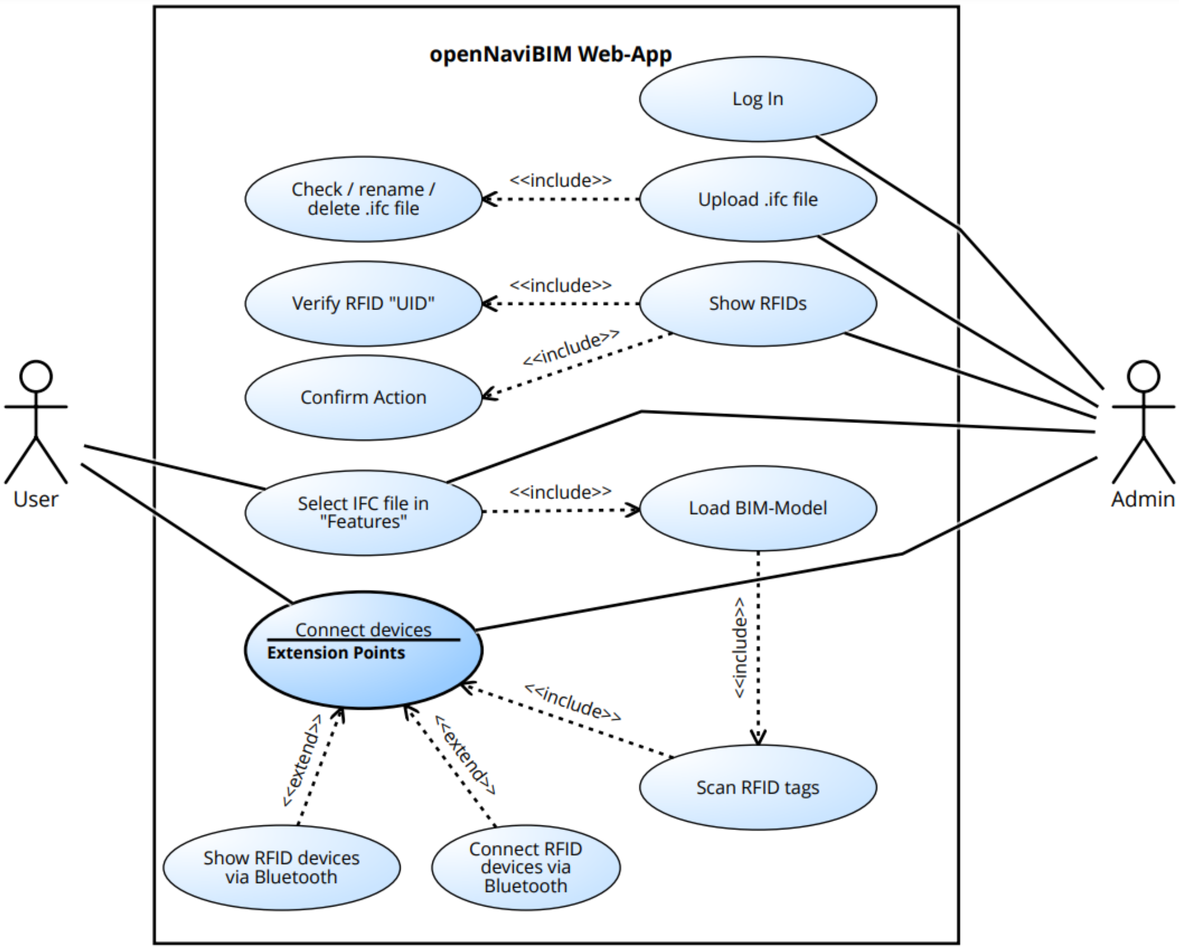


Figure 61: Use Case diagram of openNaviBIM app (Source: A. Juraboev)

In *openNaviBIM*, the administratior provides BIM models in IFC format. The client or user can load these BIM models and operate them in the app. The user can connect the app with RFID devices via Bluetooth. With the scanning of structural elements the BIM-supported information is visualised and displayed in the app.

4.4.3 Folder Structure, Functions, and Implementation of the Web-Application

The *openNaviBIM* web application consists of four main folders: Client, Imports, Public and Server (see *Figure 62*).

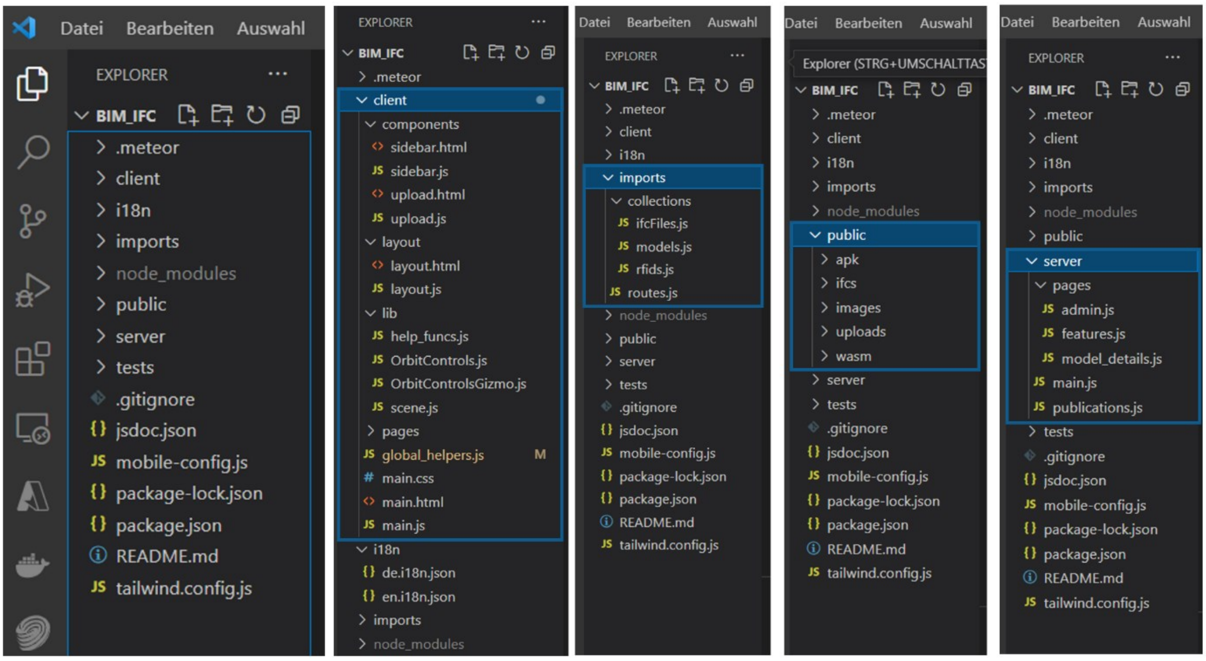


Figure 62: Folder structure of openNaviBIM Web-App (Source: A. Juraboev)

(1) Client: The *client* folder is responsible for all content that is visible to the user, such as functions, 3D rendering, audio etc.. Here you will find *pages, global_helpers.js,* as well as *main.css, main.html, main.js* and *components*.

(2) Imports: Here are the files that are used in the database (MongoDB). In *collections*, the database sets are listed in the form of lists for *ifcFiles*, model, RFID serial number "UID". *Routes.js* stands for the navigation of layouts (defined pages) in the application.

(3) Public: The *public* folder (a download folder) contains the static files that become publicly available in the application, for example APK files, IFC files for permanent loading of IFC models, images and *Web Assambly (Wasm). Wasm* is a configuration file and was used for the *IFC.js* package so that IFC models could be loaded in the application and made available in *Three.js*.

(4) Server: The *server* is responsible for the content, data management (retriever) in (from) the databases and its delivery to the *client* upon request.

In the following, the most important contents and functions of the "Client" folder are examined in more detail as follows:

The „global_helpers.js“ File

“*FlowRouter* is a routing package for Meteor. It does routing for client-side apps and does not handle rendering itself. It exposes an API for changing the URL and reactively getting data from the URL.“ [117], (see *Figure 63*).

- **Function "isActive"**

This function highlights the active menu (e.g. show route, change colour) in the side view of the platform (see *Figure 63, line 13-26*).

```
global_helpers.js
client > global_helpers.js > isActive
1   import { FlowRouter } from "meteor/ostrio:flow-router-extra";
2   //FlowRouter: Navigation-Package as Router
3
4 > /**…
13  function isActive(route, cl, param, id) {
14      var rd = route.split(".");
15      var rn = FlowRouter.getRouteName().split(".");
16      var a = true;
17      for(var i=0; i<rd.length;i++) {
18          if(rd[i] != rn[i]) a = false;
19      }
20      if(param && id) {
21          if(FlowRouter.getParam(param) != id) a = false;
22      }
23      return (a == true) ? cl : "";
24  }
25  Template.registerHelper('isActive', isActive);
26  //isActive Function to register
```

Figure 63: Function isActive (Source: A. Juraboev)

The function is responsible for loading and playing the public Google drive audio URL link (see *Figure 45*), which was already added as an attribute in the modelling phase (*4.2 Part I*) directly into the *openNaviBIM* application. For this purpose, the Google drive audio URL was extracted [118] (see *line 34, Figure 64*) and converted into an mp3 file for the direct playing in *openNaviBIM* (see *line 35, Figure 64*).

```
global_helpers.js
client > global_helpers.js > getAudoLink
1   import { FlowRouter } from "meteor/ostrio:flow-router-extra";
2   //FlowRouter: Navigation-Package as Router
3
4 > /**…
13 > function isActive(route, cl, param, id) {…
24  }
25  Template.registerHelper('isActive', isActive);
26  //isActive Function to register
27
28  /**
29   * This function normalizing the google drive audio file url to public
30   * @param {String} link Google drive audio file url
31   * @returns {String} normalized url
32   */
33  function getAudoLink(link) {
34      var result = link.match(/https:\/\/drive.google.com\/file\/d\/([a-zA-Z0-9_-]+)\//);
35      return 'https://docs.google.com/uc?export=open&id=' + result[1];
36  }
37  Template.registerHelper('getAudoLink', getAudoLink);
38
39  export default {
40      isActive: isActive,
41      getAudoLink: getAudoLink
42  }
```

Figure 64: Function getAudioLink (Source: A. Juraboev)

The “main.css, main.html, main.js” Files

HyperText Markup Language (HTML), Cascading Style Sheets (CSS) and JavaScript are the languages that control the web application. In Client, the starting points of the *openNaviBIM* application are main.css, main.html and main.js, respectively (see *Figure 65*).

Figure 65: main.html as a starting point at Client in openNaviBIM (Source: A. Juraboev)

The “Sidebar” File

“The sidebar is a graphical control element that displays various forms of information to the right or left side of an application window or operating system desktop (user interface).” [119]. In sidebar.html and sidebar.js the actions, such as login and logout of the administrator (admin), are executed in *openNaviBIM*. When the admin logs in, the admin data is automatically added to the MongoDB database, and when the admin logs out, the admin data is deleted. The data is not stored in the databases.

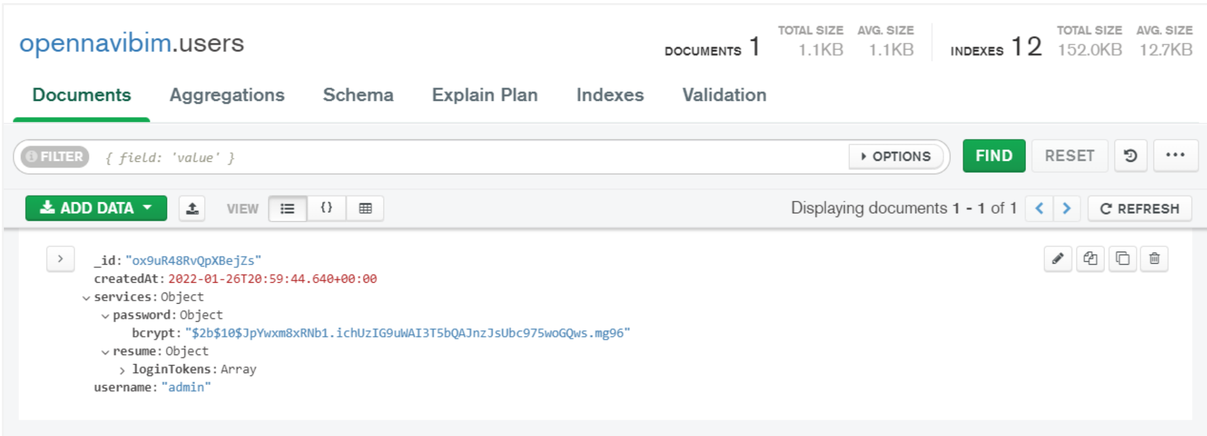


Figure 66: Database MongoDB openNaviBIM admin user data (Source: A. Juraboev)

The “Upload” File

Upload stands for uploading the IFC model via the client. When the client uploads the .IFC file to *openNaviBIM*, the file is received by the server and stored in digital Ocean Spaces (storage location or file server). Digital Ocean is a simple cloud service provider whichand it is more suitable for small applications. The digital Ocean Server offers *250 GB* of storage for *$5/month* with *1 TB* outbound. The server offers unlimited uploads and storage [120].

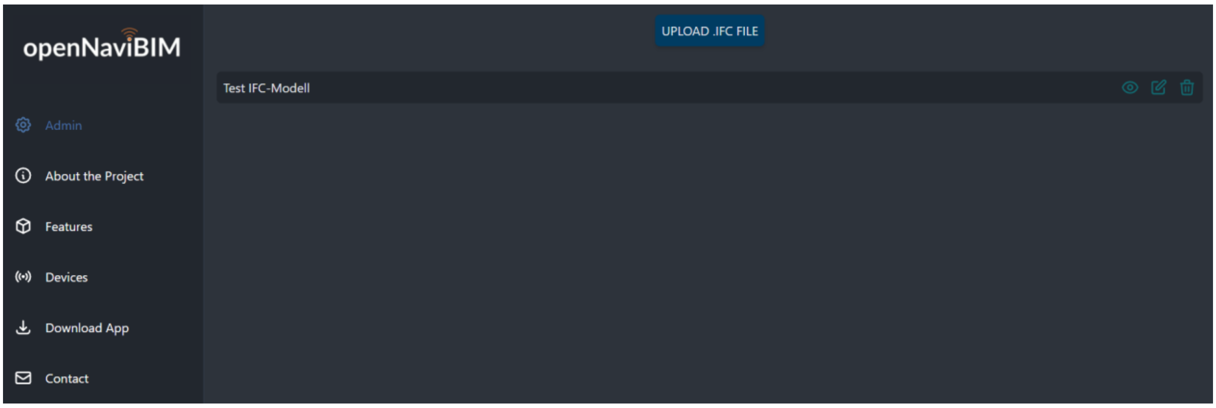


Figure 67: openNaviBIM - Admin function for uploading the IFC file (Source: A. Juraboev)

The „Scene.js“ File

The primary functions for the development of the application were carried out with the help of two packages: Three.JS and Ifc.JS. All other mentioned files served as resources to display and operate the intended visualisation in the user interface. The "Three.JS" package performs the interactions in the scene (user interface). The "Ifc.JS" package processes the IFC models (.ifc file) and provides them, as a mesh object with object information (loading and viewing), to "Three.JS" in the scene. Mesh objects are shapes consisting of triangles and vertices and are included in Three.JS packages. ThreeJS and “*OrbitContols”* were imported into the "Scene.js" file (see *Figure 68*). Through *"OrbitControls"* the visualisation scenes are displayed in the mobile app. Other imported packages [121], such as web-ifc, web-ifc-three and web-ifc-viewer.

```
scene.js
client > lib > scene.js > NewScene
import * as THREE from 'three';  //alles* aus THREE Packages import
import { OrbitControls } from '../../node_modules/three/examples/jsm/controls/OrbitControls.js'; //OrbitControls: für mobile exportieren.
import {
    acceleratedRaycast,
    computeBoundsTree,
    disposeBoundsTree,
} from "three-mesh-bvh";
import { IFCLoader } from "web-ifc-three/IFCLoader";          //Importieren von IFC-Three.js packet, web-ifc, web-ifc three,
import { OrbitControlsGizmo } from "./OrbitControlsGizmo";    //3D-Axchen-Viewer im hintergrund
import help_funcs from './help_funcs';
import { Mesh } from 'three';
/**
 * Start: Hier wurde 3D-Scene deklariert.
 */
export default class NewScene {
    /**
     * creates a new three js scene instance with all other objects like camera, controls .etc
     *
     * @param {Number} width width of canvas
     * @param {Number} height heigt of canvas
     * @param {object} el html node object
     * @param {object} div html node object
     */
    constructor(width, height, el, div) {
        this.size = {
            width: width,
            height: height,
            aspect: width / height
        }
```

Figure 68: Imported packages into the "Scene.js" (Source: A. Juraboev)

In "Scene.js", for example, a new scene was declared using the object-oriented method in which, depending on the application (web browser, tablet or mobile app), the width, height and aspect ratio of the screen are modified (see beginning of line 24, *Figure 69*). In "Scene.js" further constructors (camera, light) and the method for the coordinate representation of IFC models, were declared. The declaration of the "IF-ELSE" statement, using the asynchronous method "async loader" to select and display specific 3D objects (IFC models) with a specified camera position in the scene (UI), is shown in *Figure 69*.

```
scene.js
client > lib > scene.js > NewScene > loader
    */
    async loader(new_scene, url) {
        this.ifcLoader.ifcManager.setupThreeMeshBVH(
            computeBoundsTree,
            disposeBoundsTree,
            acceleratedRaycast
        );
        if (Meteor.isCordova) {                                              //Mobile App
            await this.ifcLoader.ifcManager.setWasmPath('../../wasm/');      //wasm-Web Assambly Datei von IFC.js auslesen für THREE.js
            this.ifcLoader.load(url, (ifcModel) => {                         //IFC-Instanz von ifc.js holen, methode load download url von ifc modell
                if (this.ifcModels.length > 0) {                             //wenn ein modell in der Scene haben,
                    this.scene.remove(this.ifcModels[0]);
                }
                this.ifcModels.push(ifcModel);
                this.scene.add(ifcModel);                                    //IFC-Modell in der Scene hochgeladen
                this.zoomCameraToSelection(new_scene.camera, new_scene.controls, ifcModel);      // modell zoom coordinaten
            });
        } else {                                                                       //Web-browser, wegen wasm-Datei.
            await this.ifcLoader.ifcManager.setWasmPath("../wasm/");
            this.ifcLoader.load(url, (ifcModel) => {
                if (this.ifcModels.length > 0) {
                    this.scene.remove(this.ifcModels[0]);
                    this.ifcModels = [];
                }
                this.ifcModels.push(ifcModel);
                this.scene.add(ifcModel);
                this.zoomCameraToSelection(new_scene.camera, new_scene.controls, ifcModel, 0.75);
            });
        }

    }
```

Figure 69: The "Async loader" method for loading and displaying IFC models in User Interface (Source: A. Juraboev)

The *Figure 70* shows a "highlight function" in the scene. This function will act on an event on the user's side in the current scene when the application interacts with a double click.

The "*getBoundingClientRect()"* method returns a "DOMRect" object containing information about the size of an element and its position relative (bounded) to the viewport.

The main functions for selecting and displaying IFC model property sets in the application have been declared as follows (see Figure 3):

Line 155: The search/finding of the geometry object in the scene.

Line 156: Saving "ExpressId" of the selected object in the scene.

Line 157: Using "ID", all property sets (*getPropertySet*, true) of the first uploaded IFC model (0) are stored in the scene and visualised when interacting with a mouse click.

Line 158-159: Deploy IFC model property sets "Properties" in the scene.

scene.js

client > lib > scene.js > NewScene > highlight

```
    /**
     *
     * @param {Object} event mouse click event on canvas
     * @param {NewScene} new_scene NewScene Class instance from actual scene
     * @returns {Mesh} selected mesh object
     */

    async highlight(event, new_scene) {
        const bounds = new_scene.el.getBoundingClientRect();
        if (Meteor.isCordova) {
            var x1 = event.touches[0].clientX - bounds.left;
            var x2 = bounds.right - bounds.left;
            var y1 = event.touches[0].clientY - bounds.top;
            var y2 = bounds.bottom - bounds.top;
        } else {
            var x1 = event.clientX - bounds.left;
            var x2 = bounds.right - bounds.left;
            var y1 = event.clientY - bounds.top;
            var y2 = bounds.bottom - bounds.top;
        }
        new_scene.mouse.x = (x1 / x2) * 2 - 1;
        new_scene.mouse.y = -(y1 / y2) * 2 + 1;
        // Places it on the camera pointing to the mouse
        new_scene.raycaster.setFromCamera(new_scene.mouse, new_scene.camera); //Raycaster position definition
        // Casts a ray
        const found = new_scene.raycaster.intersectObjects(new_scene.ifcModels)[0];
        if (found) {
            // Gets model ID
            // Gets Express ID
            const index = found.faceIndex;
            const geometry = found.object.geometry;
            const id = new_scene.ifcLoader.ifcManager.getExpressId(geometry, index);
            const props = await new_scene.ifcLoader.ifcManager.getPropertySets(0, id, true);
            Session.set('expressid', id);
            Session.set('props', props);
            // Creates subset
            console.log(new_scene);
```

Figure 70: Highlight function elements (Source: A. Juraboev)

The "model_details.js" File

- **Function „buildRFID“**

In this function (see *Figure 71)* the RFID tag objects (child elements) created in IFC models were identified with the help of the proxy function *"IfcBuildingElementProxy"* and compiled in a table. Afterwards, the identified RFID tag objects were assigned to the corresponding component elements (parent elements), (corresponding to *chapter 4.2.5*). This is the function describes: Search in the IFC model for all elements of the type *"IfcBuildingElementProxy"* and create the RFID list with the associated property sets of the elements found (such as identification number, audio data).

model_details.js

client > pages > model_details.js > 'dblclick canvas#threeCanvas'

```
    'dblclick canvas#threeCanvas': async function (event, template) {
        event.preventDefault();
        await template.scene.get().highlight(event, template.scene.get());
    },
    /**
     * click button and show elements, than assign RFIDs to the parent elements.
     * @param {*} event
     * @param {*} template
     */
    'click button#show_elements': async function (event, template) {
        event.preventDefault();
        /**
         * clear lists
         */
        const temp = Template.instance();
        temp.children.set([]);
        temp.RFIDS.set([]);
        var proxys = await temp.scene.get().ifcLoader.ifcManager.getAllItemsOfType(0, IFCBUILDINGELEMENTPROXY, true);

        /**
         *
         * @param {*} rfid
         * @param {*} properties
         * @returns
         */
        function buildRFID(rfid, properties) {
            properties.forEach(h => {
                if (h.Name.value == 'Audio' && h.NominalValue.value != '') {
                    rfid["audio"] = h.NominalValue.value;
                }
                if (h.Name.value == 'RFID_TAG_ID') {
                    rfid["_id"] = h.NominalValue.value;
                }
            });
            return rfid;
        }
```

Figure 71: IfcBuildingElementProxy with the property sets in the Deploy scene (Source: A. Juraboev)

- **Function „proxy.forEach“**

The IF Loop "forEach" was used to filter the list of RFID property sets. In this variable, the child element was linked to the parent element using the parameters (ID data) of the IFC object and the "expressID" (see *Figure 72*).

model_details.js

client > pages > model_details.js > 'click button#show_elements' > proxys.forEach() callback

```

        proxys.forEach(async element => {
            //get getItemProperties
            var prop = await temp.scene.get().ifcLoader.ifcManager.getItemProperties(0, element.expressID, false);
            if (prop.Name.value.includes('RFID')) {
                var propSet = await temp.scene.get().ifcLoader.ifcManager.getPropertySets(0, element.expressID, true);
                var rfid = {
                    name: prop.Name.value,
                    propSet: propSet
                }
                propSet.forEach(p => {
                    if (p.Name.value == 'ID-Daten') {
                        var tmp = template.RFIDS.get();
                        tmp.push(buildRFID(rfid, p.HasProperties));
                        template.RFIDS.set(tmp);
                    }
                });

            }
        });
```

Figure 72: Assignment of the attribute "RFID" from the "ID-Data" with expressID (Source: A. Juraboev)

4.4.4 The Communication of the Hardware Components

The Web app *openNaviBIM* in smart mobile devices that support Wi-Fi, Bluetooth and/or NFC functions are follows:

- The NFC tags can be scanned directly by smartphones using the NFC function.
- The UHF tags can be scanned with UHF RFID or UHF PDA readers and connected to the mobile smartphone via Bluetooth.

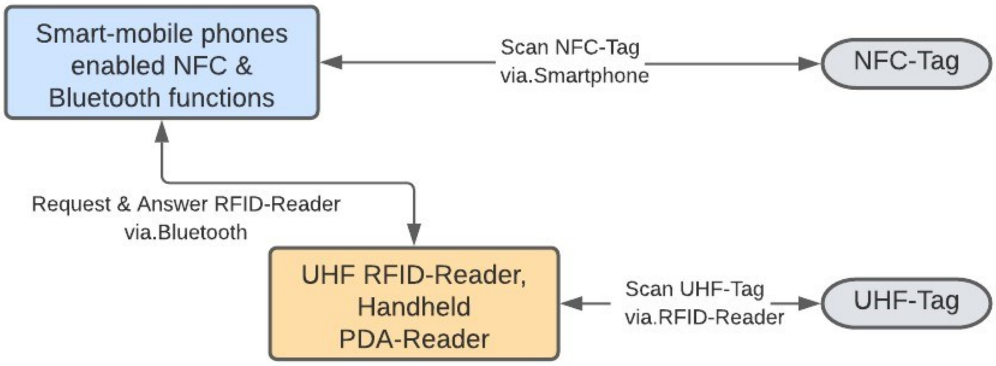


Figure 73: Communication of the devices and transponders via the app (Source: A. Juraboev)

4.5 Simulation and Performance of Tests

4.5.1 Simulation Using the Application

Tests were carried out with the developed web application and the usability results are presented in tabular form. They serve to evaluate the accessibility and the control of the functions and the content of the web app. The simulation and the tests were carried out in a browser and in the web app on a mobile smartphone.

To use the IFC model, the steps described in *4.2 Part I and 4.3 Part II* must be carried out step by step for the proof of concept. The open-source test IFC model "THM_Campus_E15.ifc" is 16.3 MB (equivalent to 17,174,528 bytes) in size. The model was exported in *IFC 2x3 Coordination View 2.0* with the highest level of detail.

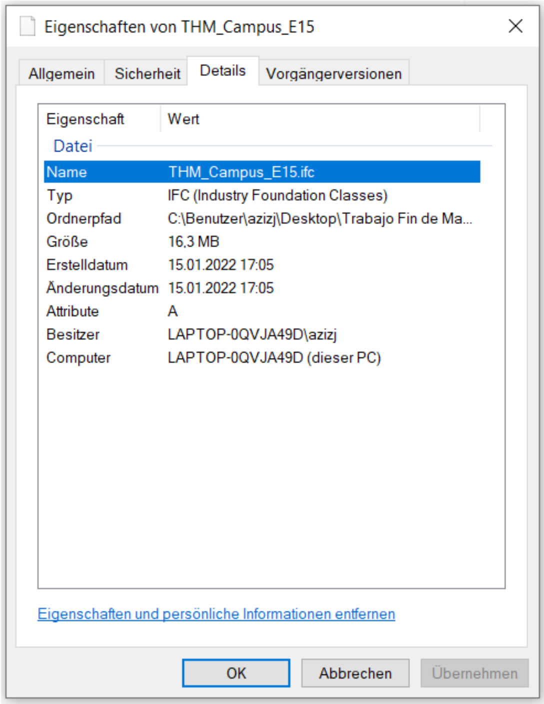


Figure 74: Details of test model to simulate the results (Source: A. Juraboev)

4.5.2 Simulation of IFC Model in the Application

a) Browser Application - “Admin“ View

The IFC model "THM_Campus_E15" was uploaded to the *openNaviBIM* web application from the administrator’s point of view. The admin uploads the IFC model to the server via the client, the IFC model is stored on the server and can be downloaded by the users via "Features" on the admin side. The following time durations, which depend on the file size, were calculated as follows:

- Duration of uploading IFC model to *openNaviBIM*: 6.72 sec. (see *Figure 67*).
- Display duration of IFC model: 14.14 sec.
- Duration of the assignment from child elements (RFID UID) to parent elements: 01 min, 57.30 sec.

As it takes a long time to assign the RFID UID to the parent element (step 3), the process is interrupted and a maintenance message is displayed (see *Figure 75*).

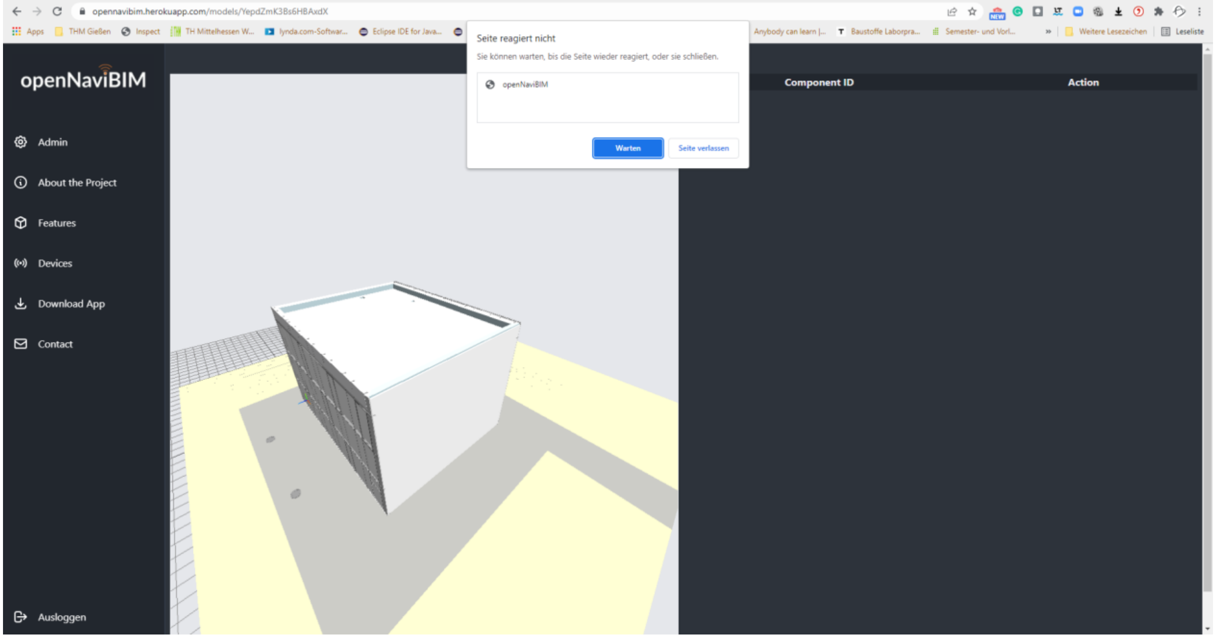


Figure 75: The process of assigning RFID UIDs to parent elements (Source: A. Juraboev)

After the process was completed, the action was confirmed and RFID UIDs were assigned to component IDs, at the time the RFID UID is scanned. All ownership records are summarised and visualised in table with “Properties” (see *Figure 77*).

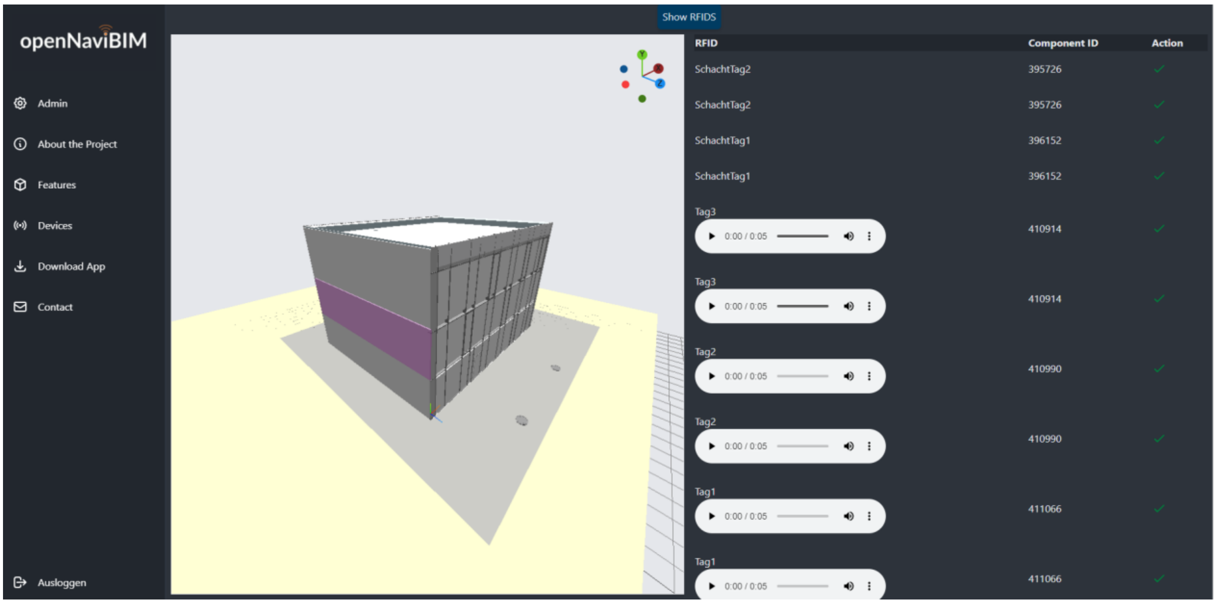


Figure 76: Assigning RFID UID to the parent component ID (Source: A. Juraboev)

Any IFC model based on this concept can be uploaded to the admin page.

b) Browser Application - "Features" View

Using "Features" view, the test model loaded in 8-10 seconds. With larger IFC models the screen freezes.

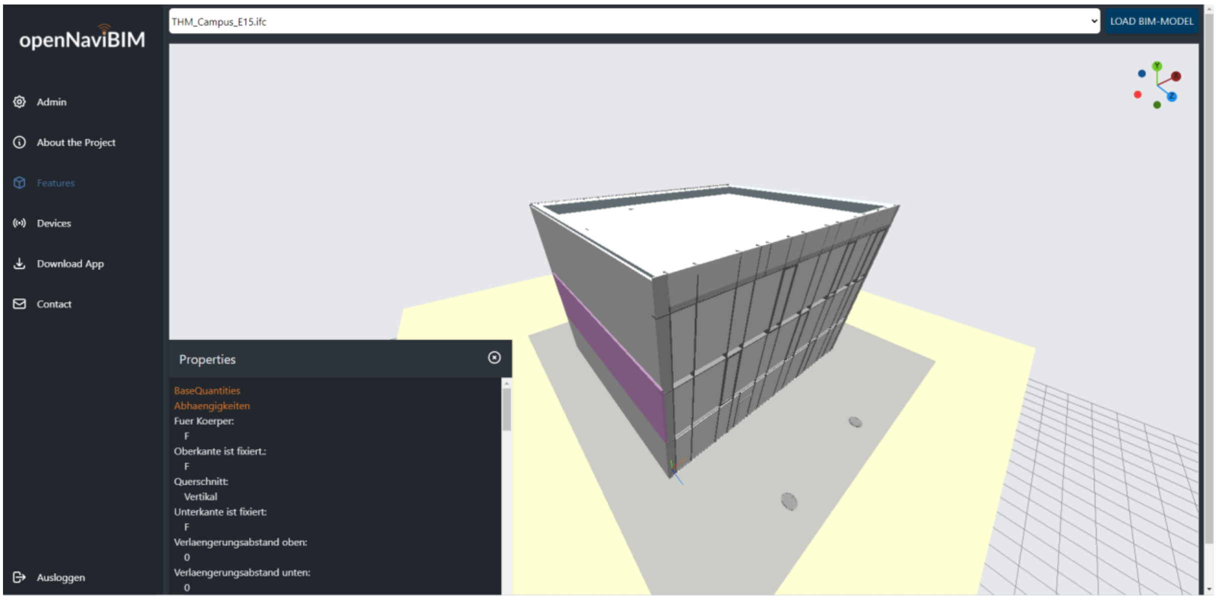


Figure 77: “Features” view of openNaviBIM in the browser (Source: A. Juraboev)

c) Web app in a Mobile Smartphone - "Features" View

The app was tested in mobile smartphones using the NFC reading function. For testing purposes, the serial number of the NFC tags was first integrated as an attribute in the Revit project. The process is the same as for RFID tags, however, the NFC tags can be read directly with most Android smartphones that support NFC.

Loading the IFC model in the app using "Features" currently takes about 30 seconds. If the IFC model is large, the app sometimes freezes and has to be restarted.

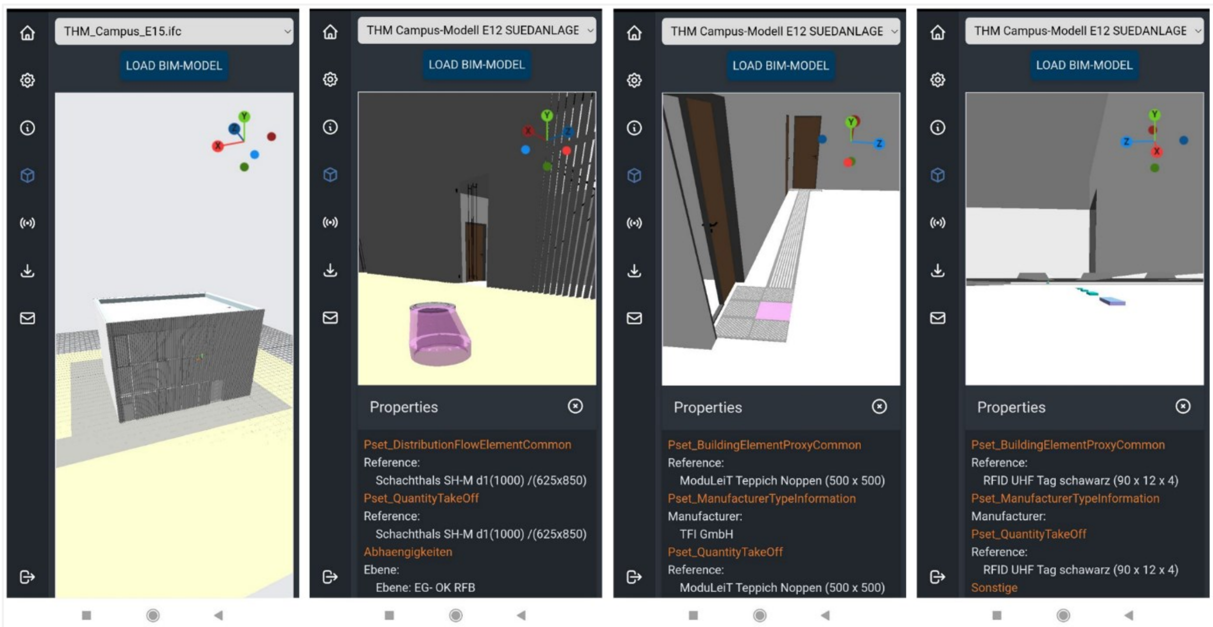


Figure 78: Features view of openNaviBIM in the web app on a mobile Android smartphone (Source: A. Juraboev)

As shown in *Figure 78*, when NFC or RFID tags are scanned in the web app, the property sets (Properties) are displayed visually and the audio message, if available, is played.

4.6 Summary of the Results

The special about this approach is that the integration of innovative technologies, such as RFID, Sensors, Internet of Things, etc., into physical building elements, structures and virtual BIM models provides a basis for structure-oriented information management. It creates a high level of transparency by assigning all BIM-based, manufacturing, planning, construction and operational information to the building. By reading the tagged building elements (see *Figure 79*), complete information assigned to BIM models can be retrieved and made available to users visually and auditorily in an application.

In this work, the implementation of RFID (UHF, NFC), Wi-Fi, Bluetooth, as well as a Cloud-based, open-source prototype application was practically investigated using the example of a PoC and made available in a Cloud platform (https://opennavibim.herokuapp.com/) as a demo version.

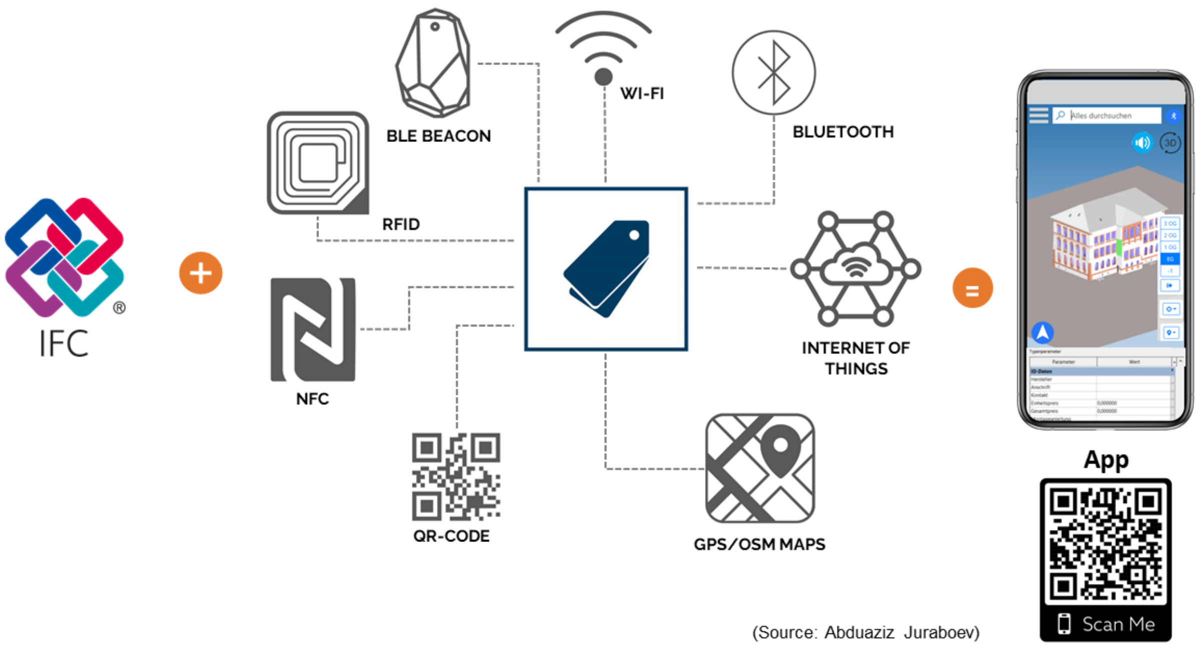


Figure 79: Integration of RTLS and IoT technologies into digital BIM models and physical building elements for connectivity (Source: A. Juraboev)

By tagging three-dimensional BIM models with physical building structures using sensor technologies in a cross-platform application, the active use of BIM models is enabled by the facility management and the public during project planning, construction, and the life cycle of the buildings and infrastructure objects.

5 DISCUSSION

5.1 Interpretation of the Results

In this study, the Integration of RFID and wireless IoT technologies into BIM models was investigated, and a “Proof of Concept” for software applications and hardware solutions was generated. This was accomplished by developing a web application for the purpose of navigation, location and information systems using *openNaviBIM.*

In the literature research numerous technologies for the implementation of the software frameworks, which were partly derived during the development phase of the web application in the practical part of the work, were examined. The development of the *openNaviBIM* web application was based on IfcJS, a JavaScript library for loading, displaying and editing IFC models. In addition to IfcJS, an already existing toolkit, xbim, a .NET open-source software development for BIM models, was used, as described in Chapter 2.8.4 for the project "SSAIM". Since 2021 IfcJS is in an early development phase and it is a good alternative with open source frameworks to develop a web and mobile application (hybrid app). The unique feature of IfcJs is the possibility to use IFC models without converting them and to deploy BIM models to the public with an open-source Approach.

By using hybrid applications, the BIM models can constantly be checked by the administrator(s) (facility manager(s)) and, if necessary, updated and made available to the users (Public) according to their requirements. For this purpose, it would have been much more practical if this preliminary work had been done in a desktop application, rather than in a smartphone mobile application. Furthermore, in practice, the use of open-source web applications is widespread, especially since the deployment of Cloud-based service solutions using the API. In this project, for example, digital the Ocean Service API was used to make the IFC files available in the Cloud and to enable their access by the client in real-time.

In the Web-app *openNaviBIM* the data will be stored by the client in the MongoDB (a document-oriented database system) using CRUD (Create, Read, Update and Delete) operations. MongoDB is open-source NoSQL based database and is better for big data transactions with faster process. Reference was made to this part of the project in Chapter 2.5.3.

The research results show that by integrating RFID tags, as BIM objects, into building elements during the planning phase, the physical objects can be linked to digital BIM models with the help of “RFID tag” component families, using a serial numbers to specific coordinates. The developed application is available for connecting BIM models with RFID technology.

The reason for creating and integrating three-dimensional RFID tags in BIM models is that the digital BIM objects have a unique “ExpressId”. For example, several RFID tags are integrated, with a certain distance from each other, into larger building elements (e.g. a screed floor slab or a wall). Associated Information, which is dependent on the coordinate point (e.g. audio information), is described as an attribute in the RFID component family. All general building material-specific information can be assigned to the digital building objects as parameters.

In conclusion, the above mentioned metadata can be used to develop BIM, sensor and RFID based applications, not only for the development of centimetre-accurate turn-by-turn navigation and positioning systems, but also for the development of information systems in smart home applications.

5.2 Adressed Questions and Objective of this Work

The questions formulated in Chapter 1 and the defined objectives of this thesis for the outlined problems have, using intensive literature research, methodical procedures and practical tests, confirmed the following hypotheses:

- RFID tags can be inserted and uniquely identified in various building materials and components. Using unique RFID serial numbers, BIM models can be linked to physical building components through an application. The digitalisation of constructions using BIM can be, in future, complemented by GS1 standards (Global Identification Numbers) [124].
- In principle, the virtual representation (BIM model) can be linked via an application by integrating RFID tags in physical objects. However, the Auto-ID technology does not send real-time information, but sends data on demand with the help of a reader. For the development of real-time digital twins for various applications (e.g. humidity, temperature, lighting) other active sensors can be utilised and read with the same application. The procedure remains the same, only the sensor information changes.
- The generated metadata can be used to develop further individual BIM-supported navigation, positioning and information systems for mobile applications.

6 CONCLUSION AND OUTLOOK

RFID technology offers high accuracy in determining the position of objects. In addition, the battery-free tags are largely maintenance-free and have a long service life. In discussions with RFID manufacturers , it was assured that a service life of 20 to 50 years could be assumed for the tags. The passive RFID tags can be easily integrated indoors and outdoors (into all kinds of materials) and linked to database information. They can be integrated into new buildings in the industrial manufacturing process, as well as into existing infrastructure, so that their integration can offer significant added value.
For the development and practical implementation of the "Implementation of RFID- and Wireless IoT Technologies in BIM", interdisciplinary cooperation, model-oriented planning and model-based communication already play an important role in the planning phase of buildings. This means, for example, that resources over the entire life cycle of a building can not only be tracked, but the product and object data can be made transparently available for further use (e.g. tracking of structure information via RFID tag for the maintenance of the object).

The implementation of RFID and wireless IoT technologies into BIM models creates added value to the interplay of people, tools and processes during the long operation and usage phases of the structures. For the successful implementation of this project, it is necessary to involve qualified personnel. This concerns not only the qualification and willingness of the users to undergo further training, but also the acceptance of digital innovative solutions and tools in practice. To implement the above mentioned projects, a step-by-step procedure is proposed as shown in *Figure 80*.

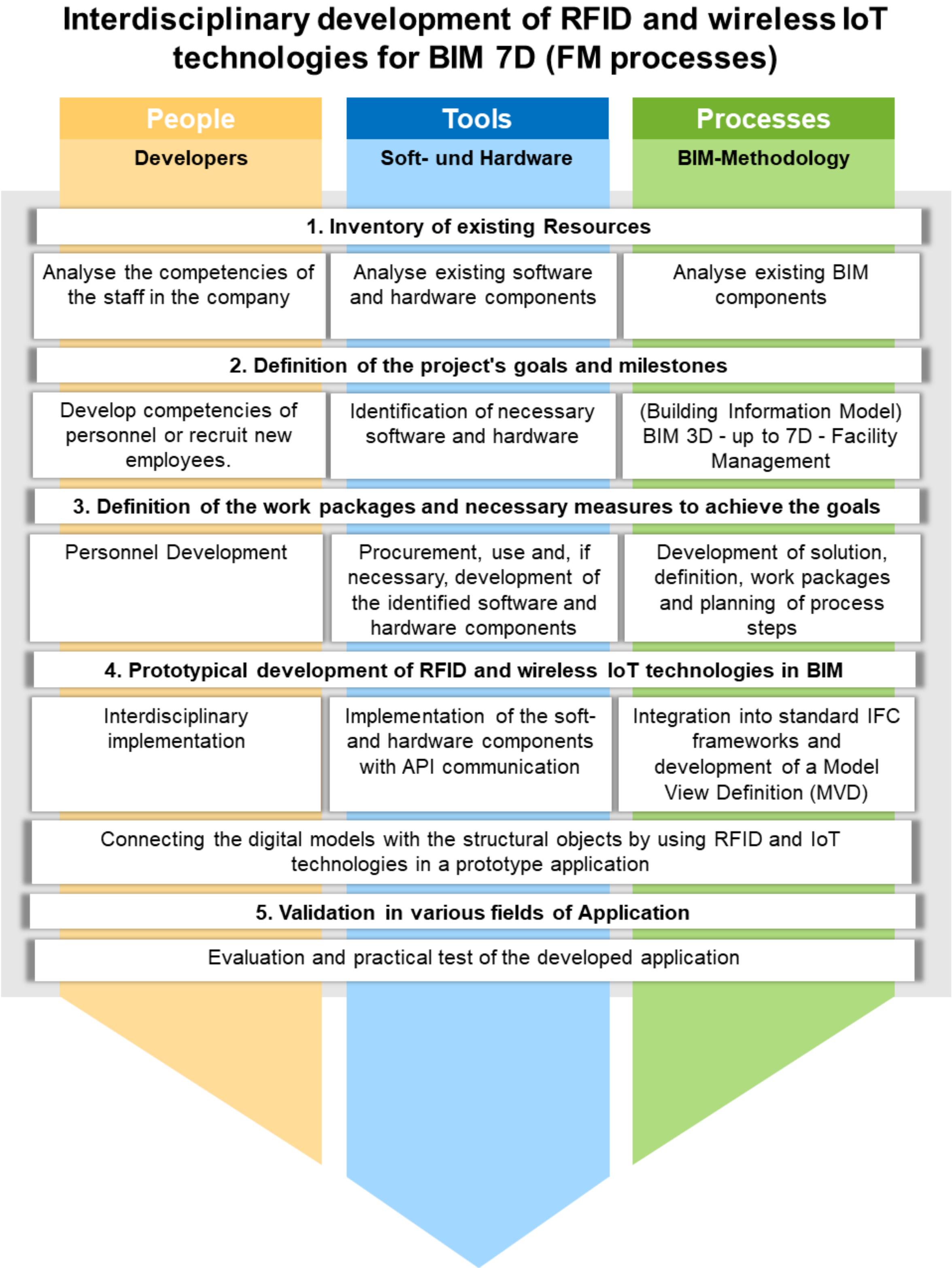


Figure 80: Interdisciplinary development of RFID and wireless IoT technologies for a BIM 7D (Source: A. Juraboev)

7 FUTURE RESEARCH PROJECTS

The aim of this master's thesis was to transfer the knowledge gained, the solution approach developed and the proof of concept for the incorporation of RFID and wireless IoT technologies into BIM, to research in the area of the outlined problems of the two use cases defined in Chapter 1. Those are:

A. Use Case 1 - Centimetre accurate pedestrian guidance system for the blind and people with limited mobility
B. Use Case 2 - Infrastructure objects in urban water management

The table below describes the proposals for research projects at the Technical University of Central Hesse (THM).

Table 10: Planned research projects at the THM, Faculty of Civil Engineering (Source: TFI GmbH, Robotic Eyes GmbH and THM: J. Díaz, R. Kern, A. Juraboev)

Use Case	**Research Topics**	**Objectives of the Future Research Projects**
1	Modular haptic, optical and RFID-based guidance system for the blind for indoor spaces based on textile floor coverings (ModuLeiT)	This research project aims to develop a design guideline for floor indicators and navigation systems for indoor use. With the help of this design guideline, textile floor coverings manufacturers can integrate 3-dimensional textile haptic and visual floor indicators into existing collections of carpet tiles. In addition, on practicality as a guidance system for the blind, the indicators should offer an aesthetic added value to the building. RFID tags (transponders) are integrated into the carpet tiles as part of an RFID system. This will be linked to the BIM models via an interface that is to be developed. On the basis of this, a navigation app, that can navigate through buildings without barriers, can be produced. In this context, design guidelines, requirements and tests for the practical suitability of the systems are being developed. The system will be validated by a demonstrator through a practical test with visually impaired people.

	BIM-based navigation and positioning system for people with limited mobility (openNaviBIM)	The objective of this project is the further development of a new form of orientation in publicly accessible buildings for visually impaired and elderly people, through the combined use of innovative technology components (Building Information Modelling (BIM), Radio Frequency Identification (RFID) and Time of Flight (ToF)). Novel ToF cameras enable GPS and beacon-free indoor positioning by determining the relative position to building walls and objects in the environment. The feasibility of combining a BIM model with a ToF-supported indoor navigation system, as well as an RFID tag embedded in the floor slab for position correction, in order to form a high-performance overall system, is to be explored before starting the project.
2	RFID-based location and maintenance of infrastructure objects in urban water management, based on the open BIM approach (RFID&BIM in Underground Infrastructure)	The objective is to promote, on the basis of non-proprietary BIM models, the digitalisation and development of RFID-supported locations and the maintenance of infrastructure objects in urban water management. The BIM-based method of working in underground facilities using innovative sensor technologies offers the possibility of reliably detecting and maintaining the objects in sewer networks and documenting them in a model-based manner. Within the framework of a research project, a secure and reliable positioning system for infrastructure objects in sewer networks, based on RFID technology, is to be researched. The proposed idea is to integrate RFID tags (transponders) into the infrastructure objects, which then can be scanned with an RFID reader and an app, and connected to BIM models. In this context, the installation of RFID tags in underground construction objects during production and in existing infrastructure objects will be investigated and the practical suitability of the systems will be tested.

APPENDIX A

```
#
# Aziz Definition File
#
# Format:
#    PropertySet:  <Pset Name>  I[nstance]/T[ype]  <element list separated by ','>
#     <Property Name 1>  <Data type>  <[opt] Revit parameter name, if different
from IFC>
#     <Property Name 2>  <Data type>  <[opt] Revit parameter name, if different
from IFC>
#     ...

PropertySet: Sonstige           I            IfcBuildingElementProxy
             Montageanleitung                Text
             Transportzustand                Text
             max. Leseabstand (on-metal)     Text
             max. Leseabstand (off-metal)    Text
             Besonderheiten                  Text
             Material                        Text
             Schutzklasse RFID-Tag           Text
             Standard                        Text
             Datenerhalt                     Text
             Betriebstemperatur in °C        Text
             Lagertemperatur in °C           Text
             Frequenzbereich in MHz          Text
             max. EPC Speicher (Bit)         Text
             max. Nutzspeicher (Bit)         Text
             Chip                            Text
             Befestigung                     Text


PropertySet: ID-Daten                  I      IfcBuildingElementProxy
             RFID Tag EPC                    Text
             Anschrift                       Text
             Hersteller                      Text
             Kontakt                         Text
             Produkttyp                      Text
             Beschreibung                    Text
             Bauelement                      Text
             Modell                          Text
             Typenkommentare                 Text
             Typenmarkierung                 Text
             Lieferzeitpunkt                 Text
             URL                             Text
             Datenblatt                      Text
             Kosten                          Text
             Einheitspreis                   Text
             OmniClass-Nummer                Text
             OmniClass-Titel                 Text
             Codename                        Text

PropertySet: Abmessungen               I      IfcBuildingElementProxy
             Neigung Haltung                 Text
             Nennweite d1                    Text
             Nenn und Außendurchmesser d1    Text
             Radius r1                       Text
             Nennweite d2                    Text
             Nenn und Außendurchmesser d2    Text
             Wanddicke t                     Text
```

```
              Radius r2                             Text
              Bauhöhe h                             Text
              Rohrleitung dr                        Text
              Variable Schachthalshöhe              Text
              Obere Abstand Leiter                  Text
              Untere Abstand Leiter                 Text
              Muffenabstand                         Text
              Glockendurchmesser dg                 Text
              Muffendurchmesser du                  Text
              Muffenlänge Iso                       Text
              h1 Gerinne                            Text
              L/H RFID-Tag                          Text
              B/L RFID-Tag                          Text
              H/B RFID-Tag                          Text
              Durchmesser RFID                      Text
              Beschichtung h                        Text
              Noppenhöhe h                          Text
              Träger h                              Text
              Vliesrücken h                         Text
              r                                     Text

PropertySet: Statische Berechnung      I      IfcBuildingElementProxy
              Gewicht (kg)                          Text

PropertySet: Daten                     I      IfcBuildingElementProxy
              Bauteilzustand                        Text
```

REFERENCES

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https://planen-bauen40.de/

https://www.aufitgebaut.de/startseite.html