Architecture
Image Studies
AIS Scientific Journal

Vol.5 , Issue 2, 2024

Digital standards and protocols for interoperability in construction systems and methodologies

Mykhailo Malykhin [1], Olha Pylypchuk [1], Viktoriya Tytok [2], Olena Emelianova [1], Alexei Tugay [1]

[1] Department of Construction Organization and Management, Kyiv National University of Construction and Architecture, 03037, Kyiv, Ukraine

[2] Department of Construction Economics, Kyiv National University of Construction and Architecture, 03037, Kyiv, Ukraine

Abstract

The relevance of this study lies in the growing need for seamless integration between various digital systems in the construction industry, driven by the increasing adoption of digital technologies. The aim of the study is to develop standards and protocols for ensuring effective interoperability and compatibility between different digital systems used in construction. To achieve this, the study applied methods of analysis, experimentation, and practical testing. Key outcomes include the creation of a unified format standard, a sensor data integration standard, and a standard for unified architectural solutions, all of which address specific interoperability challenges in data integration. Additionally, the study developed secure protocols for data transfer and protection between systems, such as computer-aided design (CAD) tools and building information models (BIM). The practical application of these standards and protocols demonstrated improved data conversion, minimized errors related to inconsistencies, and enhanced project management efficiency. The results underscore the potential of these solutions to optimize the construction process, allowing for faster and more accurate information exchange across different platforms. This study contributes to the broader understanding of how digital innovations can improve the integration and management of construction systems. The findings offer valuable insights for further research on enhancing the efficiency and competitiveness of construction companies through digital transformation.

Keywords

architectural dynamics; unification of information formats; project management; electronic modernization; infrastructure modelling.

1. Introduction

In recent years, the digitalization of the construction industry has become a key driver of innovation and efficiency. As part of this broader trend, the current study focuses on the development of standards and protocols to ensure the effective interoperability and compatibility of various digital systems used in construction. Digitalization, often referred to as "Construction 4.0," has revolutionized traditional practices by introducing advanced tools such as Building Information Modeling (BIM), computer-aided design (CAD) systems, the Internet of Things (IoT), and cloud-based project management software. These technologies enhance project efficiency, accuracy, and sustainability, addressing common challenges like project delays, cost overruns, and fragmented workflows.

Digital technologies significantly influence construction, optimising the design, management and implementation of duties. This increases efficiency, reduces costs and improves quality. The interaction of numerous digital systems ensures the processing, storage and transmission of data at all stages of the project life cycle. Important elements are automation, modelling and analysis methods that allow for informed decisions at all stages—from idea to completion of construction. In addition, digital technologies are becoming increasingly important as competition forces companies to seek new ways to increase productivity and reduce costs. However, with the growing complexity of digital technologies in construction, there is a need for effective integration of various systems and tools. The absence of unified standards and protocols for exchanging information between these systems creates barriers that complicate project management and reduce project efficiency. The problem of data inconsistency between different digital platforms leads to increased costs, delays and lower quality of results. Therefore, there is a need to develop standards and protocols that can address these issues and contribute to more effective construction project management.

For instance, Voitovych et al. (2023) developed a methodology for optimising the construction schedule for companies using deterministic mathematical methods and modelling to identify gaps in the scientific body on this topic. As a result, a method was created that provides effective management of labour resources and optimisation of resource consumption in the process of executing construction contracts. Moreover, Tytok et al. (2022) studied the impact of digitalisation on organisational and economic management tools in the construction industry. The authors noted that the introduction of digital technologies significantly improves project management and decision-making efficiency, contributing to the successful fulfilment of construction contracts. As for Tugay et al. (2019), they addressed the introduction of innovative approaches to project supervision in construction using unmanned aerial vehicles and specialised software. They determined that the use of such technologies ensures data accuracy and timely detection of delays in the execution of work, which contributes to the effective management of construction projects and reduces the risk of budget overruns. On the other hand, Quek et al. (2023) discussed the challenges associated with the fragmentation of digital approaches in the development of digital twin city technologies and proposed semantic methods of data integration to improve the exchange of information between different systems. Doe et al. (2022) emphasised the need to improve standards for programming interfaces and adapters, as well as the importance of semantic interoperability in architecture, engineering and construction systems. Moreover, Filardo et al. (2024) analysed normative framework consisting of the level of information need and data templates, and formal representations of the corresponding ontologies, emphasising the importance of standardisation to ensure the accuracy and relevance of information in digital construction. Omrany et al. (2023) provided an overview of the introduction of digital twins in the construction industry, noting eight key areas of application, including project management, safety monitoring, and energy efficiency.

In turn, Schmidt et al. (2023) explored approaches to increasing the interoperability of digital twins by transforming between different specifications and proposed a method for converting between the Digital Twin Definition Language (DTDL) and the Asset Administration Shell (AAS). At the same time, the results of the study by Duarte-Vidal et al. (2021) demonstrated that the integration of the Building Information Model (BIM), unmanned aerial vehicles and photogrammetry technologies is an effective tool for monitoring and controlling construction projects, covering all phases of the project. Jenet et al. (2024) emphasised the need for standardisation to improve the interoperability of digital systems in construction, especially in the context of the circular economy, by developing standards for integrating data on material reuse, ensuring quality and creating adapted digital formats for construction project management. Thus, the analysis of sources has revealed gaps in the study of the integration of new technologies to improve project management, standards in the context of the circular economy, as well as semantic data integration, which requires further research to ensure the effective interaction of digital systems in construction.

In general, the study aimed to determine ways to increase the interoperability of digital systems in construction by developing and implementing standards that will facilitate the integration of new technologies into project management processes. To achieve this goal, certain goals were set, namely an analysis of modern approaches to technology integration and the impact of integration on the efficiency of construction project management.

2. Materials and Methods

The study developed and implemented standards and protocols for the integration of digital systems in construction. Tools such as Computer–Aided Design, BIM and Supervisory Control and Data Acquisition (SCADA) were considered, as they are key to managing construction projects, and their integration into a single system allows for easier data exchange, more efficient design and monitoring, and reduces the risk of errors and delays in construction.

The first stage of the study was to analyse existing system interoperability issues and develop new standards and protocols. Three main standards have been developed to ensure the integration of systems: Unified Data Format Standard (UDFS), Sensor Data Integration Standard (SDIS) and Unified Architectural Solutions Standard (UASS). Three protocols were also created: Data Transfer Protocol (DTP), Integration Protocol (IP) and Data Security Protocol (DSP). For each of the standards, examples of their application in real-life scenarios were provided, showing the advantages and disadvantages of each solution.

The second stage involved the practical implementation of the developed solutions through software tools to test their effectiveness. For this purpose, the programming languages Online Python (2024) and Online JavaScript (2024) were used. Initially, the UDFS standard was implemented using Python, where a program was created to convert data from CAD and BIM systems into the UDFS format. The software algorithm included functions for receiving data from CAD, converting it, finding the corresponding elements in BIM, combining the data into a single format, and displaying the results. This demonstrated the possibility of combining heterogeneous data from two systems. The second application was created for the SDIS standard, also in Python. It simulated receiving data from SCADA systems and other monitoring systems and then converted it to SDIS format. The main function of the application was to combine data from different sources and display the result for further use. Then, the UASS standard was implemented in JavaScript. The application processed data from video surveillance systems and security sensors, combining them into the UASS format for further integration and analysis.

On the other hand, to test the operation of the DTP, IP and DSP protocols, a software module was developed using JavaScript to simulate the transmission and processing of data between systems. The programme ran in three stages: data transmission via DTP, data integration and networking via IP, and data encryption and decryption via DSP. First, an example of a simulation of data transfer between systems was shown and the data was converted into a format ready for transfer. The next step was to combine data from CAD and BIM systems and integrate the data for further use. After that, data encryption is simulated, data is converted to base64 for encryption, data decryption is simulated, and the application is demonstrated with three protocols.

3. Results

3.1. Analysis and development of standards and protocols for digital systems integration in construction

There is a growing need in construction for the integration of digital systems that include a variety of technologies, methodologies and software. Modern technologies in construction include the widespread use of digital tools such as CAD, BIM and SCADA, as well as a variety of sensors and controllers that provide more efficient project management, precision in the execution of tasks and cost savings. However, despite significant progress, there are significant interoperability issues that affect the efficiency and productivity of construction processes. As a rule, such systems operate based on different standards and protocols, which creates problems with integration. The main interoperability issues include different data formats, lack of common protocols, and different architectural approaches. Hence, many systems use different formats for storing and processing data, which renders information exchange between systems difficult. The lack of a single standard for data exchange leads to problems with integration and information sharing. In addition, different technologies can have different architectural approaches, which makes it difficult to integrate and operate together. These issues can lead to reduced project management efficiency, errors in task execution, and increased costs. Therefore, it is necessary to develop effective standards and protocols for digital technologies in the construction industry.

The first standard to analyse is a unified data format (Figure 1). Its goal is to create a single format for storing and processing data that will be supported by all major systems in construction. This format should be universal and ensure compatibility with various technologies such as CAD, BIM and SCADA. In particular, the UDFS should integrate information from different sources in a single format, which will simplify data exchange between systems, increase the accuracy of information processing and reduce the time spent on data conversion.

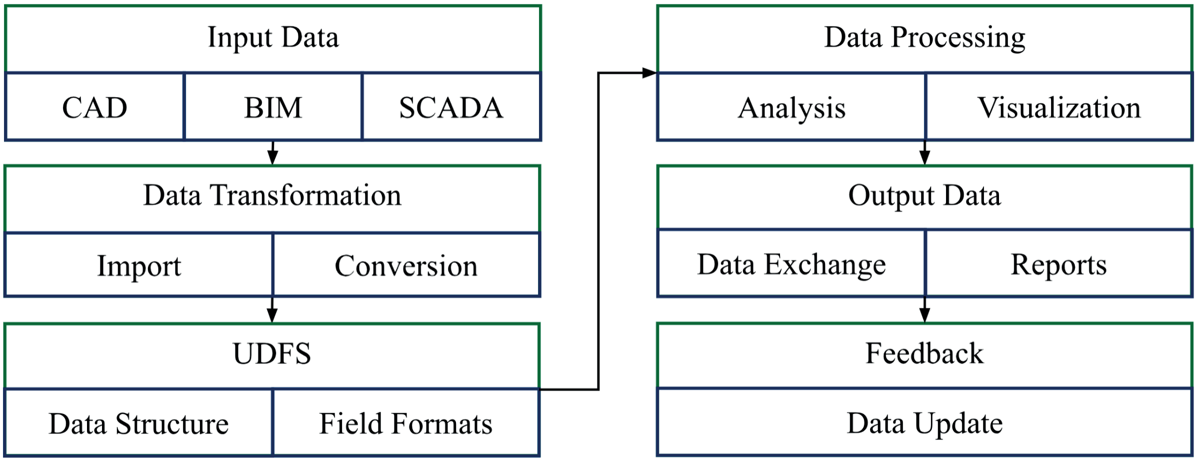

Figure 1. UDFS layout. Source: created by the authors.

UDFS can be used to effectively integrate data from various systems in construction. For instance, when designing a new commercial building, architects can create plans in a CAD system, engineers can model the building in BIM, and automation specialists can control systems via SCADA. Thanks to UDFS, all this data can be converted into a single format, which simplifies the exchange of information between systems and ensures seamless integration, increasing the accuracy and efficiency of project management.

The next standard is the integration of sensor information (Figure 2). SDIS defines common principles and formats for collecting and processing data from various sensors and devices used in construction. It includes rules for data encoding, quality management and validation, as well as for integrating sensor data with other digital systems.

Typically, construction sites use a variety of sensors to monitor humidity, temperature and motion. These sensors transmit data in real-time, but each uses a different format. The SDIS initially unifies and encodes all this data, enabling the BIM system to integrate it into the overall building information model. Thus, construction managers can receive analytical reports with accurate indicators in real time, without the need for manual data processing or conversion between different formats. It is also worth noting the standard of unified architectural solutions (Figure 3). This

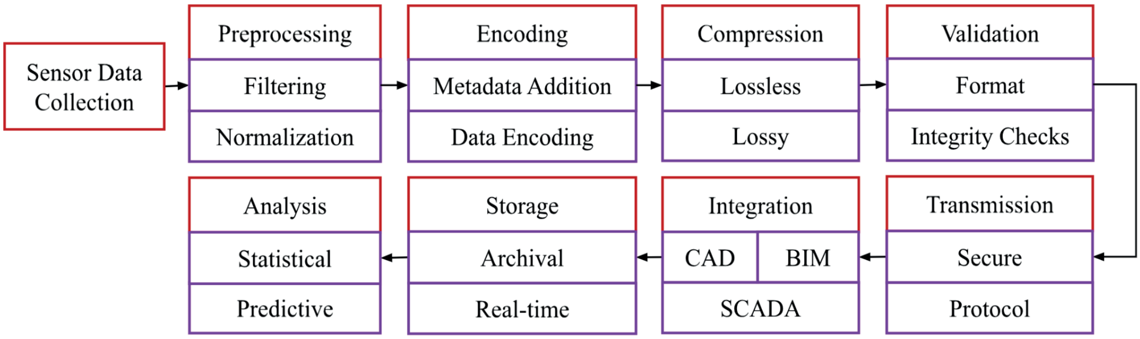

Figure 2. SDIS layout. Source: created by the authors.

standard provides for the development of unified architectural solutions that facilitate the seamless integration of various technologies and systems in construction. UASS includes the creation of unified interfaces that allow different systems to interact with each other, the development of modules for integrating different software and hardware components, and the introduction of standardised methods of information exchange. This solution facilitates the integration process, ensuring system compatibility and increasing the efficiency of construction project management.

An example of the application of the UASS standard is the integration of BIM and SCADA-based construction

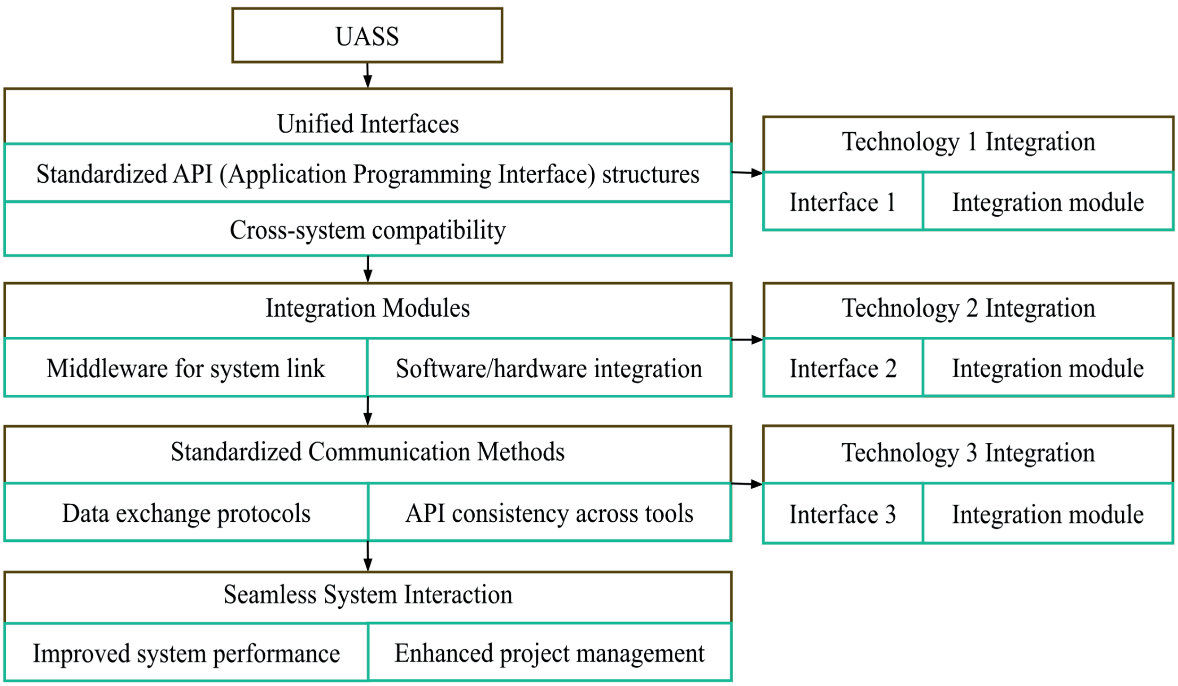

Figure 3. UASS layout. Source: created by the authors.

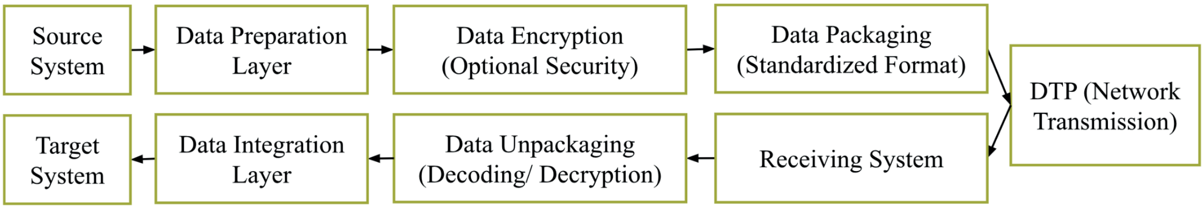

Figure 4. DTP layout. Source: created by the authors.

project management systems. The two systems can exchange data in real-time using unified interfaces that create a common architecture. Integration modules will ensure data transfer between systems, allowing the use of information on the parameters of construction objects from BIM in real conditions on the site via SCADA, and standardised communication methods will guarantee stable interaction. In addition to standards, it is necessary to implement protocols to ensure interaction between different systems in construction. For instance, a data exchange protocol will allow for the secure and reliable exchange of various types of information—structured data, graphics, and text (Figure 4). DTP ensures compatibility and correct transfer of information between different platforms, including CAD, BIM and SCADA systems, which will increase integration efficiency and reduce the risk of data loss.

Such a protocol can be used in the context of managing large construction projects where various digital systems are used. To coordinate architectural solutions, engineering data and automation systems, information must be constantly exchanged between these systems. For instance, during the design of a building, architectural models are created in CAD, while building information models are stored in BIM, and construction processes are controlled through SCADA. DTP protocol can be used to automatically transfer technical data, drawings and sensor data files between these systems in a secure and standardised format, ensuring accurate and timely information transfer without the need for manual conversion or duplication.

An integration protocol that ensures the integration of various digital systems and technologies into a single ecosystem should be highlighted (Figure 5). The main purpose of IP is to ensure efficient data exchange, and synchronisation of the states of different systems and their centralised management. The protocol allows different software and hardware solutions to interact with each other, regardless of their architecture and standards.

An example is a complex construction project that requires interaction between BIM for managing building information, CAD for technical drawings, and SCADA for monitoring and controlling construction processes in real-time. All these systems can automatically exchange

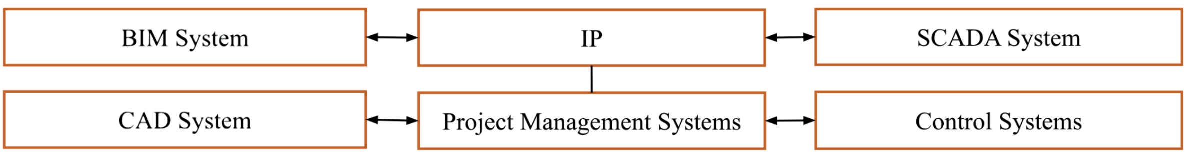

Figure 5. IP layout. Source: created by the authors.

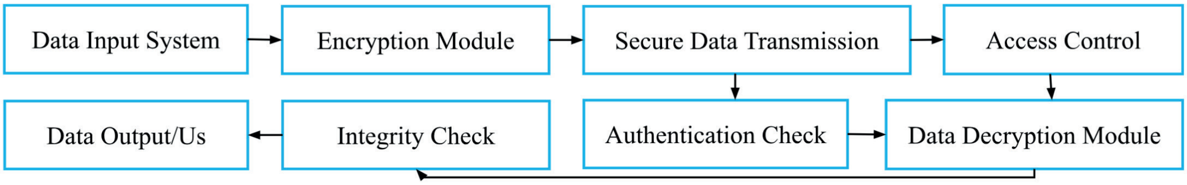

Figure 6. DSP layout. Source: created by the authors.

data and synchronise system status using IP. For instance, updates to CAD drawings are automatically synchronised with the data in BIM, avoiding incompatibilities and at the same time transmitting these changes to SCADA for real-time monitoring of task progress. Additionally, a data security protocol should be specified, which includes several important steps to ensure the security of data transmission between systems (Figure 6). The main components of DSP are data encryption, user authentication, access control, and data integrity checking, which ensures the reliability and security of the process of exchanging information between different technologies, preventing loss or unauthorised access to data.

An example is a construction project in which data related to CAD drawings is transferred to BIM for further analysis and modifications. Using DSP will ensure that the drawings are encrypted before they are sent, keeping them confidential. Users who have access to data in BIM must be authenticated, and their access to certain parts of the information will be restricted by

Standard/ Protocol	Advantages	Limitations
UDFS	Versatility, support for various systems, simplified data exchange, reduced time spent on data conversion	Requires upgrading existing systems to support the new format
SDIS	A single format for collecting data from different sensors, automating data processing, ensuring quality and accuracy	Can be difficult to implement on construction sites with a variety of sensors
UASS	Unified interfaces and modules for integration, simplified interaction between systems, increased efficiency of project management	The difficulty of developing unified architectures for different systems and technologies
DTP	Secure and reliable exchange of various types of information, ensuring compatibility between different platforms	High implementation cost to ensure support for all data formats
IP	Centralised process management, synchronisation of system states, efficient integration of various digital solutions	Difficulty in integrating with existing architectures and systems
DSP	Data protection through encryption, authentication and access control, protection against data loss or unauthorised access	Slower data exchange due to additional checks and encryption

Table 1. Comparison of standards and protocols by advantages and limitations. Source: created by the authors.

an access control system. This will minimise the risk of confidential information leakage and protect the project from external attacks or errors. Thus, the standards and protocols under consideration are significant in improving the efficiency, reliability and safety of construction project management. Their implementation will help to integrate various digital systems, ensure uninterrupted information exchange between them, and minimise the risks of data loss or errors in processes. At the same time, each of these approaches has its advantages and limitations, which should be addressed when choosing a specific solution for a particular project (Table 1).

Thus, the standards and protocols developed, such as UDFS, SDIS, UASS, DTP, IP and DSP, are critical for the integration of digital systems in construction. They enable the efficient exchange of information between different systems, including CAD, BIM and SCADA, which increases accuracy, reduces costs and improves project management. However, an equally important step is the practical application and evaluation of these protocols and standards.

3.2. Practical implementation of the developed standards and protocols

The implementation of the standards and protocols is a key step in ensuring their effective implementation in construction processes. One of these important standards is UDFS, which can be used to combine information from different sources into a single structure, which facilitates further automation. For clarity, an example of an application that converts data to the UDFS format is presented:

```
def get_cad_data():
    cad_data = [
        {“element_id”: 1, “coordinates”: [0, 0, 0]},
        {“element_id”: 2, “coordinates”: [1, 0, 0]},
        {“element_id”: 3, “coordinates”: [1, 1, 0]},
        {“element_id”: 4, “coordinates”: [0, 1, 0]},
    ]
    return cad_data

def get_bim_data():
    bim_data = [
        {“element_id”: 1, “material”: “concrete”, “thickness”: 0.3, “color”: “gray”},
        {“element_id”: 2, “material”: “steel”, “thickness”: 0.05, “color”: “silver”},
        {“element_id”: 3, “material”: “glass”, “thickness”: 0.01, “color”: “transparent”},
        {“element_id”: 4, “material”: “brick”, “thickness”: 0.2, “color”: “red”},
    ]
    return bim_data

def convert_to_udfs(cad_data, bim_data):
    udfs_data = []

    for cad_element in cad_data:
        corresponding_bim_element = next((b for b in bim_data if b[“element_id”] == cad_element[“element_id”]), None)

        if corresponding_bim_element:
            udfs_element = {
                “element_id”: cad_element[“element_id”],
                “coordinates”: cad_element[“coordinates”],
                “material”: corresponding_bim_element[“material”],
                “thickness”: corresponding_bim_element[“thickness”],
                “color”: corresponding_bim_element[“color”]
            }
            udfs_data.append(udfs_element)

    return udfs_data

def display_udfs_data(udfs_data):
    print(“UDFS Data Format (Unified):”)
    For element in udfs_data:
        print(f”Element ID: {element[‘element_id’]}”)
        print(f”  Coordinates: {element[‘coordinates’]}”)
        print(f”  Material: {element[‘material’]}”)
        print(f”  Thickness: {element[‘thickness’]}m”)
        print(f”  Color: {element[‘color’]}”)
        print(“-” * 30)

if __name__ == “__main__”:
    cad_data = get_cad_data()
```

```
    bim_data = get_bim_data()
    udfs_data = convert_to_udfs(cad_data, bim_data)

    display_udfs_data(udfs_data)
```

This application illustrates how data from different digital systems such as CAD and BIM can be combined into a single UDFS format. First, it receives data from each system: CAD provides information on the geometric coordinates of elements, while BIM provides information on the materials, thickness and colour of each element. The software then compares the data from the two sources, finds the relevant items by their identifiers, and then combines the information into a single format.

The result of the programme is the creation of a single data structure in the UDFS format, which combines information from different sources (Figure 7). In this format, each element has unified data: its unique identifier, geometric coordinates from CAD and material properties (material, thickness, colour) from BIM. This unification facilitates further data processing, which is an important part of the automation of construction processes. The result demonstrates how different systems can be integrated into a single standard to

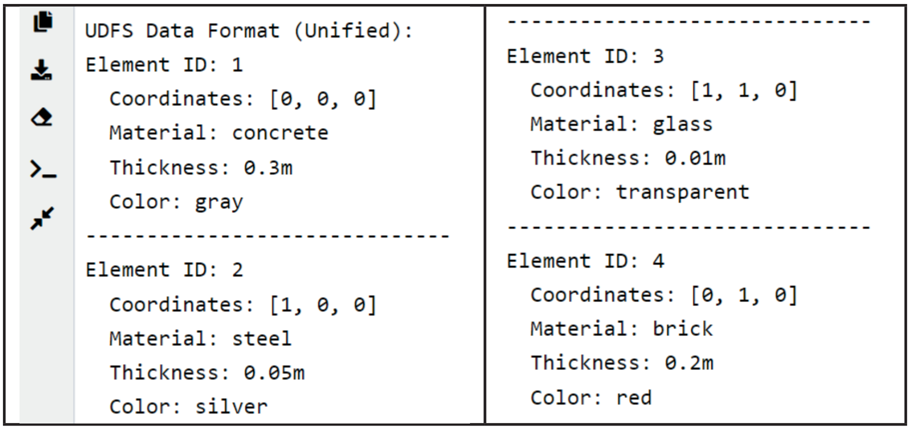

Figure 7. The result of the UDFS programme. Source: created by the authors.

increase their interoperability and efficiency.

As for SDIS, this standard allows for the effective combination of data from various sources, such as SCADA and other monitoring systems, which facilitates their integration into a single structure. An example of an application for combining information from a SCADA system and an additional monitoring system to create a single SDIS format:

```
def get_scada_data():
    scada_data = [
        {"sensor_id": 101, "value": 22.5, "unit": "Celsius", "timestamp": "2024-09-18 10:00"},
        {"sensor_id": 102, "value": 45.8, "unit": "Percentage", "timestamp": "2024-09-18 10:01"},
        {"sensor_id": 103, "value": 70.2, "unit": "Bar", "timestamp": "2024-09-18 10:02"},
    ]
    return scada_data

def get_monitoring_data():
    monitoring_data = [
        {"sensor_id": 101, "location": "Room 1", "status": "Active"},
        {"sensor_id": 102, "location": "Room 2", "status": "Active"},
        {"sensor_id": 103, "location": "Boiler Room", "status": "Warning"},
    ]
```

```
    return monitoring_data

def convert_to_sdis(scada_data, monitoring_data):
    sdis_data = []

    for scada_element in scada_data:
        corresponding_monitoring_element = next((m for m in monitoring_data if m[“sensor_id”] == scada_element[“sensor_id”]), None)

        if corresponding_monitoring_element:
            sdis_element = {
                “sensor_id”: scada_element[“sensor_id”],
                “value”: scada_element[“value”],
                “unit”: scada_element[“unit”],
                “timestamp”: scada_element[“timestamp”],
                “location”: corresponding_monitoring_element[“location”],
                “status”: corresponding_monitoring_element[“status”]
            }
            sdis_data.append(sdis_element)

    return sdis_data

def display_sdis_data(sdis_data):
    print(“SDIS Data Format (Unified):”)
    for element in sdis_data:
        print(f”Sensor ID: {element[‘sensor_id’]}”)
        print(f”  Value: {element[‘value’]} {element[‘unit’]}”)
        print(f”  Timestamp: {element[‘timestamp’]}”)
        print(f”  Location: {element[‘location’]}”)
        print(f”  Status: {element[‘status’]}”)
        print(“-” * 30)

if __name__ == “__main__”:
    scada_data = get_scada_data()
    monitoring_data = get_monitoring_data()

    sdis_data = convert_to_sdis(scada_data, monitoring_data)

    display_sdis_data(sdis_data)
```

The application combines data from the SCADA system, which provides sensor readings (temperature, pressure, humidity, etc.), with data from another monitoring system, which contains additional information about the location of sensors and their status. It converts this data into a single SDIS format, which can be used to integrate all the important parameters for each sensor into a unified structure. The result is a data structure in the SDIS format that combines the technical data from the sensors in the SCADA with additional data from another

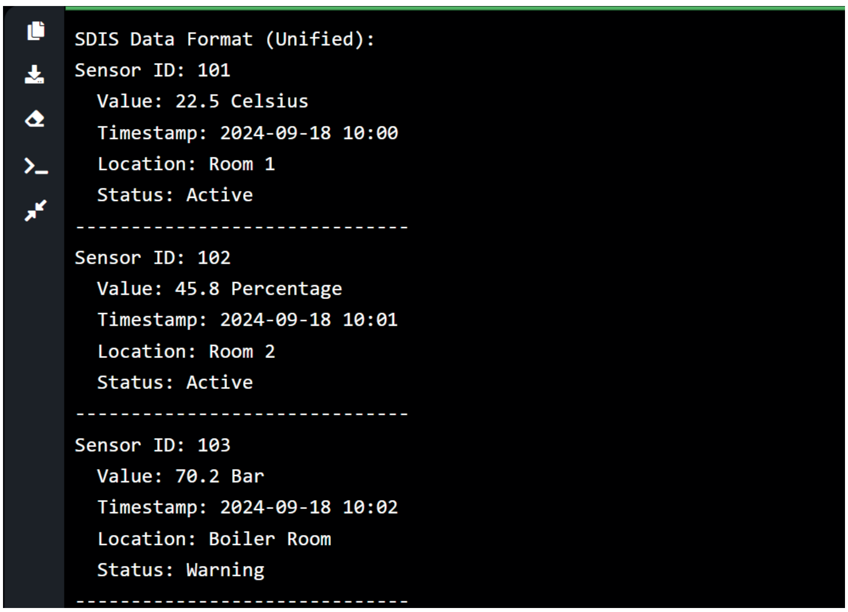

Figure 8. The result of the SDIS programme. Source: created by the authors.

monitoring system (Figure 8). This unification of data allows for a higher level of control and automation at construction sites, ensuring effective monitoring of the facilities' condition and prompt response to changes.

In addition, UASS can be used to unify data from different systems to control and monitor assets. This helps to integrate information from various sources to centrally monitor asset health, security and effective management. This standard applies to the fusion of data from video surveillance systems and security sensors in facilities. UASS can be used to combine video information with additional data, such as alarms or device status. A code sample that demonstrates how to work with UASS to combine video surveillance and security sensor data:

```
const videoSurveillanceData = [
 { cameraId: 1, timestamp: "2024-09-18 10:00", footage: "video1.mp4" },
 { cameraId: 2, timestamp: "2024-09-18 10:05", footage: "video2.mp4" },
 { cameraId: 3, timestamp: "2024-09-18 10:10", footage: "video3.mp4" }
];

const securitySensorData = [
  { sensorId: 1, location: "Entrance", status: "OK", alert: false },
 { sensorId: 2, location: "Warehouse", status: "Warning", alert: true },
 { sensorId: 3, location: "Office", status: "OK", alert: false }
];

function mergeToUASS(videoData, sensorData) {
 let uassData = [];

 videoData.forEach(video => {
   let correspondingSensor = sensorData.find(sensor => sensor.sensorId === video.cameraId);

   if (correspondingSensor) {
     let uassElement = {
       cameraId: video.cameraId,
       footage: video.footage,
       timestamp: video.timestamp,
       location: correspondingSensor.location,
       status: correspondingSensor.status,
       alert: correspondingSensor.alert
     };
     uassData.push(uassElement);
   }
 });

 return uassData;
}

function displayUASSData(uassData) {
 console.log("UASS Data Format (Unified):");
 uassData.forEach(element => {
   console.log(`Camera ID: ${element.cameraId}`);
   console.log(`  Footage: ${element.footage}`);
   console.log(`  Timestamp: ${element.timestamp}`);
   console.log(`  Location: ${element.location}`);
   console.log(`  Status: ${element.status}`);
   console.log(`  Alert: ${element.alert ? "Yes" : "No"}`);
   console.log("--------------------------------");
 });
}

let uassData = mergeToUASS(videoSurveillanceData, securitySensorData);
displayUASSData(uassData);
```

This application shows how to combine information from video surveillance and security sensors into a single UASS format. First, data is obtained from both systems: video cameras provide recordings, and sensors report on security conditions. The software combines this data by their respective identifiers to create a unified structure that includes both video and sensor data. The result is a view of the state of the object with unified data (Figure 9). Each camera provides not only video footage but also information about the state of the respective object or place. This can be used to effectively monitor the security of facilities and respond quickly to potential threats.


```
node /tmp/ZOUadP2Csf.js
UASS Data Format (Unified):
Camera ID: 1
  Footage: video1.mp4
  Timestamp: 2024-09-18 10:00
  Location: Entrance
  Status: OK
  Alert: No
------------------------------
Camera ID: 2
  Footage: video2.mp4
  Timestamp: 2024-09-18 10:05
  Location: Warehouse
  Status: Warning
  Alert: Yes
------------------------------
Camera ID: 3
  Footage: video3.mp4
  Timestamp: 2024-09-18 10:10
  Location: Office
  Status: OK
  Alert: No
------------------------------
```

Figure 9. The result of the UASS programme. Source: created by the authors.

In addition, to ensure efficient, integrated and secure data exchange between different building technology systems, three protocols (DTP, IP and DSP) can be implemented in a single application. An application that demonstrates how to combine functionality for data transfer, integration and protection, which are key to ensuring interoperability of different systems in construction processes:

```
class DTP {
  static transfer(data) {
    console.log("DTP: Transferring data...");
    return JSON.stringify(data);
  }
}

class IP {
  static integrate(cadData, bimData) {
    console.log("IP: Integrating CAD and BIM data...");
    let integratedData = [];

    cadData.forEach(cadElement => {
      let bimElement = bimData.find(b => b.element_id
=== cadElement.element_id);
      if (bimElement) {
        integratedData.push({
          element_id: cadElement.element_id,
          coordinates: cadElement.coordinates,
          material: bimElement.material,
          thickness: bimElement.thickness,
          color: bimElement.color
        });
      }
    });

    return integratedData;
  }
}
```

```
class DSP {
  static encrypt(data) {
    console.log("DSP: Encrypting data...");
    return btoa(data);
  }

  static decrypt(encryptedData) {
    console.log("DSP: Decrypting data...");
    return atob(encryptedData);
  }
}

function runProtocolDemo() {
  const cadData = [
    { element_id: 1, coordinates: [0, 0, 0] },
    { element_id: 2, coordinates: [1, 0, 0] },
    { element_id: 3, coordinates: [1, 1, 0] }
  ];

  const bimData = [
    { element_id: 1, material: "concrete", thickness: 0.3, color: "gray" },
    { element_id: 2, material: "steel", thickness: 0.05, color: "silver" },
    { element_id: 3, material: "glass", thickness: 0.01, color: "transparent" }
  ];

  const integratedData = IP.integrate(cadData, bimData);
  console.log("Integrated Data:", integratedData);

  const transferredData = DTP.transfer(integratedData);
  console.log("Transferred Data:", transferredData);

  const encryptedData = DSP.encrypt(transferredData);
  console.log("Encrypted Data:", encryptedData);

  const decryptedData = DSP.decrypt(encryptedData);
  console.log("Decrypted Data:", JSON.parse(decryptedData));
}

runProtocolDemo();
```

In this application, DTP is responsible for transferring data between systems. Data from integrated systems is transferred in JSON format to ensure compatibility and standardisation between CAD, BIM and SCADA platforms. A protocol such as IP combines data from two different systems. It finds the relevant elements in both systems by their identifiers and integrates them into a single structure containing geometry and material data. In turn, the DSP ensures security during data transmission. In this case, the data is encrypted before transmission, which guarantees its confidentiality. It can also be used to decrypt the data for further use. The programme demonstrates the integration of data between CAD and BIM systems, the transfer of this data in a standardised format, and encryption for security during transmission:

```
IP: Integrating CAD and BIM data...
Integrated Data: [
  {
    element_id: 1,
    coordinates: [ 0, 0, 0 ],
    material: 'concrete',
    thickness: 0.3,
    color: 'gray'
  },
  {
    element_id: 2,
    coordinates: [ 1, 0, 0 ],
    material: 'steel',
    thickness: 0.05,
    color: 'silver'
  },
  {
    element_id: 3,
    coordinates: [ 1, 1, 0 ],
    material: 'glass',
    thickness: 0.01,
    color: 'transparent'
  }
]
DTP: Transferring data...
Transferred Data: [{"element_id":1,"coordinates":[0,0,0],"material":"concrete","thickness":0.3,"col-
```

or":"gray"},{"element_id":2,"coordinates":[1,0,0],"material":"steel","thickness":0.05,"color":"silver"},{"element_id":3,"coordinates":[1,1,0],"material":"glass","thickness":0.01,"color":"transparent"}]

DSP: Encrypting data...
Encrypted Data:
W3siZWxlbWVudF9pZCI6MSwiY29vcmRpbmF0ZX-
MiOlswLDAsMF0sIm1hdGVyaWFsIjoiY29uY3Jld-
GUiLCJ0aGlja25lc3MiOjAuMywiY29sb3IiOiJncm-
F5In0seyJlbGVtZW50X2lkIjoyLCJjb29yZGluYXRlcy-
I6WzEsMCwwXSwibWF0ZXJpYWwiOiJzdGVlbCIs-
InRoaWNrbmVzcyI6MC4wNSwiY29sb3IiOiJzaWx-
2ZXIifSx7ImVsZW1lbnRfaWQiOjMsImNvb3JkaW5h-
dGVzIjpbMSwxLDBdLCJtYXRlcmlhbCI6ImdsYXNzIi-
widGhpY2tuZXNzIjowLjAxLCJjb2xvciI6InRyYW5zcG-
FyZW50In1d

DSP: Decrypting data...
Decrypted Data: [
```
  {
    element_id: 1,
    coordinates: [ 0, 0, 0 ],
    material: 'concrete',
    thickness: 0.3,
    color: 'gray'
  },
  {
    element_id: 2,
    coordinates: [ 1, 0, 0 ],
    material: 'steel',
    thickness: 0.05,
    color: 'silver'
  },
  {
    element_id: 3,
    coordinates: [ 1, 1, 0 ],
    material: 'glass',
    thickness: 0.01,
    color: 'transparent'
  }
]
```

=== Session Ended. Please Run the code again ===

The use of these protocols allows for reliable, secure and standardised interaction between digital systems, which is critical for managing complex construction projects where different platforms are used. Thus, the practical application of the developed standards and protocols demonstrates their effectiveness and importance for modern construction processes, providing automation, integration and information security, which are key factors for the successful management of complex engineering projects.

4. Discussions

The findings of the study highlighted the importance of ensuring interoperability between digital technologies and the construction sector, which is critical to optimising project management processes and increasing overall efficiency. Comparison of the results with similar studies in this area is a necessary aspect, as it allows for a deeper understanding of current trends and issues arising in the context of this topic.

In general, the results of this study confirmed the importance of developing new standards and protocols for the integration of digital systems in construction, which is similar to the results of Korodi et al. (2024), which pointed out the possibility of integrating outdated building management systems using modern technologies. Abdelalim et al. (2024) also confirmed that the use of the latest technologies together with agent-based modelling methods can significantly improve the efficiency of resource management on construction sites, which is consistent with the results of the current work, as both approaches are aimed at optimising project management and improving the integration of digital technologies into construction processes.

The results confirmed the importance of creating a unified data format for the integration of digital systems in construction, which is comparable to the study by Rojas Meléndez et al. (2021), which used semantic technologies for the construction of railway infrastructure, as both studies focused on data integration to ensure interoperability. Results of a study by Ghansah and Edwards (2024) demonstrated the trend of using digital technologies for quality assurance in construction, with an emphasis on the integration of new technologies, which correlates with the results of the current work, which also pointed to the introduction of new standards to improve project management processes. In addition, the study by Chen et al. (2021) demonstrated the importance of ensuring the compatibility of protocols and data models for interoperability between equipment vendors. The results of the study also confirmed the importance of creating integration standards in construction, but they focus on data unification and information security. The results of this study also highlighted the importance of removing barriers to the integration of digital technologies in construction, which is consistent with the findings of Sofolahan et al. (2024), which identified financial and infrastructure barriers in the construction sector that made it difficult to adapt technologies. Compared to the study of Wang et al. (2022), which emphasised the need to standardise terms and architectures for digital twins, the results of the current work focused on the creation of unified data formats that would allow for easier exchange of information between systems and increase the efficiency of project management.

In turn, the results of the study, which highlighted the importance of ensuring the integration of digital technologies in construction, are consistent with the results of Kievit et al. (2023), which showed a systems-based modelling approach to improve information exchange in infrastructure projects. Whereas the results of Johari et al. (2024) demonstrated the impact of digital technologies on project management in construction, through the study of digital technologies in organisations, the current work, on the contrary, emphasised the need for specific standards to optimise the use of digital technologies in project management. Compared to the results of Tong and Ma (2021), who emphasised the importance of developing standards for the construction of digital museums, the conducted study focused on the integration of digital technologies into construction, proposing more general standards. While the results of this study highlighted the importance of developing standards for the integration of digital systems in construction, Aiduang et al. (2024) emphasised the standardisation of testing of environmentally friendly building materials. Both studies highlighted innovation in the construction sector but focused on different aspects. However, unlike the results of the current study, which focused on integration standards specifically in the construction industry, the other study looked at a wider range of digital platforms. Moreover, the results confirmed the importance of standardisation for the integration of digital systems in construction, which is consistent with the study by Barbu et al. (2024) who focused on interoperability in the context of digital transformation. However, the current study developed specific protocols adapted to the needs of the construction sector. Saad et al. (2023) pointed out the potential for technology integration in Industry 4.0, but they did not focus on the specific standards that were developed in this paper to improve digital information management. On the other hand, the results of the current work are consistent with the conclusions of Adams et al. (2024) about the importance of new life cycle models, but the emphasis is on the need for data unification, which significantly increases the efficiency of project management.

At the same time, the conclusions of the study by Zhang et al. (2024) addressed the architecture of platforms for the construction of smart cities and the role of digital twins in reducing the development cycle. Instead, the current study did not address digital twins but developed common protocols for the integration of digital systems in construction, which increases the efficiency of project management in the construction industry. Khodabakhshian (2024) examined the impact of technology on construction efficiency, emphasising the social implications. The study complemented this topic by emphasising the importance of data unification and specific standards for the integration of digital technologies into construction processes. Lastly, a study by Aliu and Oke (2023) identified key benefits of digitalisation in construction, including increased operational efficiency and productivity. At the same time, the results of the current work have demonstrated not only the benefits but also the limitations of technology adoption in the construction sector. In addition, Fonseca et al. (2024) showed that the integration of Lean Construction and BIM improves data management but faces implementation challenges. The current study also considered BIM technologies, but together with SCADA and CAD, emphasising the importance of integrating these systems to achieve greater efficiency. The results of the work of Lucchi (2023) emphasised the importance of digital twins and new technologies, which is in line with the current work, which also raised integration issues, in particular data unification, which is critical for the successful implementation of new technologies in the construction industry.

Thus, the results of this study not only confirmed the existing achievements in the field of digital technology integration in construction but also significantly expanded knowledge about the specifics of creating standards and protocols adapted to the needs of this industry. Unlike many studies that have focused only on the general aspects of technology adoption, this study highlighted the importance of data unification and specific standards that can significantly improve project management. The study provided a deeper understanding of integration processes and highlighted practical solutions to overcome existing barriers in the construction sector, making it an important contribution to the development of the topic of digital technology integration.

5. Conclusions

The study determined that the integration of digital technologies into the construction sector is critical to improving project management efficiency. Based on the analysis of modern tools, such as building information modelling systems, computer-aided design, and data monitoring and collection systems, it is confirmed that the introduction of new standards and protocols can significantly reduce the number of errors associated with data incompatibility.

The study developed several key standards and protocols, including a unified data format, a data integration standard, a unified architectural framework, a data transfer protocol, an identification protocol, and a data security protocol. These standards and protocols promote the unification of information formats, which ensures better interoperability between different systems, reducing the likelihood of errors during data transmission and processing.

Based on the findings, it is recommended to develop training programmes for staff covering new standards and technologies to ensure their effective implementation. It is also necessary to introduce regular monitoring and evaluation of the effectiveness of new standards in real projects to identify possible problems at an early stage. It would be advisable to expand research on the relationship between digital technologies and sustainable development in the construction sector, particularly the impact on environmental performance. In addition, the standards should include recommendations for adapting to the rapidly changing technological environment, including new digital solutions and platforms.

However, the study also had certain limitations. First, the impact of certain technologies, such as the Internet of Things and artificial intelligence, on the implementation of the developed standards was not considered. Moreover, the sample size for testing the developed protocols was limited, which may affect the overall conclusions. For further research, it is worth addressing the impact of various technologies on construction processes, as well as on improving existing standards and protocols to adapt them to new conditions. This will open new opportunities for improving management practices in the construction sector and ensuring their compliance with modern requirements.

References

Abdelalim, A.M., Said, S.O., Alnaser, A.A., Sharaf, A., Elsamadony, A., Kontoni, D.-P.N., Tantawy, M., 2024. Agent-based modeling for construction resource positioning using digital twin and BLE technologies, Buildings, 14(6), 1788. https://doi.org/10.3390/buildings14061788

Adams, K.M., Ibrahim, I., Krahn, S., 2024. Engineering systems with standards and digital models: Development of a 15288-SysML grid. Systems, 12(8), 276. https://doi.org/10.3390/systems12080276

Aiduang, W., Jinanukul, P., Thamjaree, W., Kiatsiriroat, T., Waroonkun, T., Lumyong, S., 2024. A comprehensive review on studying and developing guidelines to standardize the inspection of properties and production methods for mycelium-bound composites in bio-based building material applications, Biomimetics, 9(9), 549. https://doi.org/10.3390/biomimetics9090549

Aliu, J., Oke, A.E., 2023. Construction in the digital age: Exploring the benefits of digital technologies, Built Environment Project and Asset Management, 13(3), 412-429. https://doi.org/10.1108/BEPAM-11-2022-0186

Barbu, M., Vevera, A.V., Barbu, D.C., 2024. Standardization and interoperability – Key elements of digital transformation., in: Cioca, L.I., Ivascu, L., Filip, F.G., Doina, B. (Eds.), Digital Transformation: Technology, Tools, and Studies, in: Cham, Springer, pp. 87-94. https://doi.org/10.1007/978-3-031-55952-5_5

Chen, L., Li, H., Charton, T., Zhang, R., 2021. Virtual digital substation test system and interoperability assessments, Energies, 14(8), 2337. https://doi.org/10.3390/en14082337

Doe, R., Kaur, K., Selway, M., Stumptner, M., 2022. Interoperability in AECO and the oil & gas sectors: Object-based standards and systems, Journal of Information Technology in Construction, 27, 312-334. https://doi.org/10.36680/j.itcon.2022.016

Duarte-Vidal, L., Herrera, R.F., Atencio, E., Rivera, F.M., 2021. Interoperability of digital tools for the monitoring and control of construction projects, Applied Sciences, 11(21), 10370. https://doi.org/10.3390/app112110370

Filardo, M.M., Liu, L., Hagedorn, P., Zentgraf, S., Melzner, J., König, M., 2024. A standard-based ontology network for information requirements in digital construction projects, in: LDAC2024: Linked Data in Architecture and Construction Workshop, in: Bochum, Linked Data in Architecture and Construction, accessible at https://www.uni-weimar.de/fileadmin/user/fak/bauing/professuren_institute/Baubetrieb_und_Bauverfahren_2022/Publikationen/LDAC2024_Camera_8_v02.pdf

Fonseca, S.S., Benito, P.A., Ramírez, C.P., 2024. Digital horizons in construction: A comprehensive system for excellence in project management, Buildings, 14(7), 2228. https://doi.org/10.3390/buildings14072228

Ghansah, F.A., Edwards, D.J., 2024. Digital technologies for quality assurance in the construction industry: Current trend and future research directions towards Industry 4.0, Buildings, 14(3), 844. https://doi.org/10.3390/buildings14030844

Jenet, A., Lamperti Tornaghi, M., Tsionis, G., Sejersen, A., Moseley, P., de la Fuente Nuno, A., Wrobel, M., Hobbs, G., Guldager Jensen, K., Chevauché, C., Levy, M.H., Osset, P., Denton, S., Ottosen, L.M., Lynch, J., Lewis, M., Fuchs, M., Mian, L., Maurer, P., Taucer, F., 2024. Circular technologies in construction – Putting science into standards, accessible at https://data.europa.eu/doi/10.2760/876431

Johari, M.S., Mahmud, S.H., Mohamed, S.F., Misnan, M.S., Kamarudin, T., Mat Dzahir, M. A., Utama, W.P., 2024. Digitalization: Potentials of digital technology capabilities in the construction industry, Journal of Advanced Research in Applied Sciences and Engineering Technology, 50(1), 136-150. https://doi.org/10.37934/araset.50.1.136150

Khodabakhshian, A., 2024. Ethics-aware application of digital technologies in the construction industry, in: Chiodo, S., Kaiser, D., Shah, J., Volonté, P. (Eds.), Improving Technology Through Ethics, in: Cham, Springer, pp. 49-64. https://doi.org/10.1007/978-3-031-52962-7_5

Kievit, H., Bazuin, B., Keatley, O., Ralphs, H., Ubels, S., 2023. Enriching model-based systems engineering with interoperability through master data: A case study of High Speed 2 (UK) and Flemish Tunnel Standard (Belgium), in: INCOSE Annual Systems Engineering Conference. https://doi.org/10.5281/zenodo.10257907

Korodi, A., Nițulescu, I.-V., Fülöp, A.-A., Vesa, V.-C., Demian, P., Braneci, R.-A., Popescu, D., 2024. Integration of legacy industrial equipment in a building-management system Industry 5.0 scenario, Electronics, 13(16), 3229. https://doi.org/10.3390/electronics13163229

Lucchi, E., 2023. Digital twins for the automation of the heritage construction sector, Automation in Construction, 156, 105073. https://doi.org/10.1016/j.autcon.2023.105073

Omrany, H., Al-Obaidi, K.M., Husain, A., Ghaffarianhoseini, A., 2023. Digital twins in the construction industry: A comprehensive review of current implementations, enabling technologies, and future directions, Sustainability, 15(14), 10908. https://doi.org/10.3390/su151410908

Online JavaScript Compiler., 2024, accessible at https://www.programiz.com/javascript/online-compiler/.

Online Python – IDE., 2024, accessible at https://www.online-python.com/.

Quek, H.Y., Sielker, F., Akroyd, J., Bhave, A.N., Von Richthofen, A., Herthogs, P., Van Der Laag Yamu, C., Wan, L., Nochta, T., Burgess, G., Lim, M.Q., Mosbach, S., Kraft, M., 2023. The conundrum in smart city governance: Interoperability and compatibility in an ever-growing ecosystem of digital twins, Data & Policy, 5, e6. https://doi.org/10.1017/dap.2023.1

Rojas Meléndez, J.A., Aguado, M., Vasilopoulou, P., Velitchkov, I., Van Assche, D., Colpaert, P., Verborgh, R., 2021. Leveraging semantic technologies for digital interoperability in the European railway domain, in: Hotho, A., Blomqvist, E., Dietze, S., Fokoue, A., Ding, Y., Barnaghi, P., Haller, A., Dragoni, M., Alani, H. (Eds.), Proceedings of the 20th International Semantic Web Conference "The Semantic Web – ISWC 2021", in: Cham, Springer, pp. 648-664. https://doi.org/10.1007/978-3-030-88361-4_38

Saad, A., 2023. Digital technologies for construction circular economy, in: Salford Postgrafuate Annual Research Conference. Book of Abstracts 2023, in: Salford, University of Salford, p. 23, accessible at https://www.researchgate.net/publication/378747390_Digital_Technologies_for_Construction_Circular_Economy

Schmidt, C., Volz, F., Stojanovic, L., Sutschet, G., 2023. Increasing interoperability between digital twin standards and specifications: Transformation of DTDL to AAS, Sensors, 23(18), 7742. https://doi.org/10.3390/s23187742

Sofolahan, O., Eze, E.C., Ameyaw, E.E., Nnametu, J., 2024. Barriers to digital technologies – Driven circular economy in the Nigerian construction industry, Smart and Sustainable Built Environment. https://doi.org/10.1108/SASBE-11-2023-0357

Tong, Y., Ma, Y., 2021. Digital museum construction standards study, International Archives of the Photogrammetry Remote Sensing and Spatial Information Sciences, 46(1), 753-760. https://doi.org/10.5194/isprs-archives-XLVI-M-1-2021-753-2021

Tugay, O., Zeltser, R., Kolot, M., Panasiuk, I., 2019. Organization of supervision over construction works using UAVs and special software, Science and Innovation, 15(4), 21-28. http://doi.org/10.15407/scine15.04.021

Tytok, V., Emelianova, O., Galinsky, O., Lysytsia, N., Malykhin, M., 2022. Organisational and economic tools for managing investment programmes involving construction enterprises through digitalisation, Review of Economics and Finance, 20, 1060-1066, accessible at https://refpress.org/ref-vol20-a118/

Voitovych, V., Emelianova, O., Tytok, V., Pokolenko, V., Pylypchuk, O., 2023. Optimization of the load of production units of the construction company, WSEAS Transactions on Information Science and Applications, 20, 228-237. https://doi.org/10.37394/23209.2023.20.26

Wang, K., Wang, Y., Li, Y., Fan, X., Xiao, S., Hu, L., 2022. A review of the technology standards for enabling digital twin, Digital Twin, 2, 4. https://doi.org/10.12688/digitaltwin.17549.1

Zhang, J., Gao, W., Wang, S., 2024. Research on smart city platform construction technology for digital twins, International Journal of Advanced Network Monitoring and Controls, 9(2), 1-10. https://doi.org/10.2478/ijanmc-2024-0011