Development of a Prototype Data-system Integration Platform for As-Built Inspection

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Abstract –

This study focuses on developing a data-system integration platform tailored for the construction phase. It employs application programming interfaces (APIs) and a range of sensor devices to enhance construction management practices. The platform is crafted to cater to various requirements while maintaining scalability, utilizing a microservice architecture to facilitate seamless integration with external systems. A prototype of the platform was developed and subsequently assessed for its practicality in as-built inspections, receiving positive evaluations for its effectiveness and efficiency. Additionally, the platform showed its adaptability by successfully integrating with external services for comprehensive analysis and data collection. Future endeavors will focus on customizing the platform for diverse applications and collaborating with stakeholders to foster its practical implementation in construction projects.

Keywords –

APIs; As-built inspection; Integration platform

1 Introduction

The rapid advancement of sensor technology in recent years has greatly facilitated the collection of crucial data for construction management from worksites. This development, coupled with the progression of applications designed for data analysis and processing, suggests a trend toward the tailored combination and usage of these devices and applications to meet the specific needs of various construction projects. application programming interfaces (APIs) are a key method for combining these technological tools. However, challenges arise when system integration occurs in a one-to-one relationship between API providers (e.g., device developers) and users (e.g., application developers), as depicted in Figure 1 (above). To address this issue, the integration platform illustrated in Figure 1 (below) is proposed. This study focuses on developing a prototype data-system integration platform for the construction phase, aiming to enable the seamless integration of devices and applications.

A critical aspect of developing a data system integration platform is defining requirement specifications based on user needs. The objective of this study is to specify the system requirements for a data-system integration platform targeting the construction phase, develop a prototype, and assess its effectiveness through practical application.

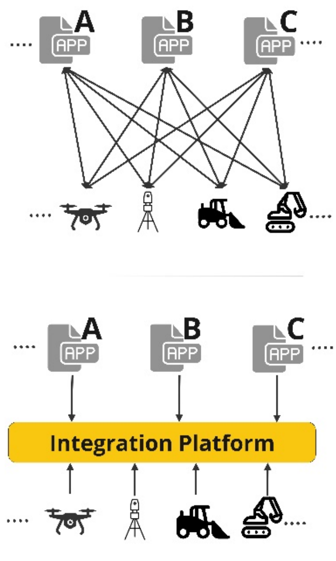

Figure 1. Comparison of device and application collaboration with and without an integration platform (above: without platform, below: with platform).

2 What is data-system integration platform

The evolution of integration platforms is a global phenomenon. Notable examples include DATA-EX [1] and the Connector Architecture for Decentralized Data Exchange (CADDE) [2] in Japan, and GAIA-X [3] and the International Data Spaces Association (IDSA) [4] internationally. Industry-specific integration platforms are emerging in sectors such as agriculture [5], smart cities [6], and the energy sector [7].

Moreover, the proliferation of cloud computing technologies has led to diverse service offerings, including infrastructure as a service (IaaS), platform as a service (PaaS), and software as a service (SaaS) [8]. Gartner, a leading American consulting firm, defines integration platform as a service (iPaaS) [6] as a comprehensive suite of cloud services that facilitates the development, execution, and governance of integration flows. These services enable the connection of a variety of on-premises and cloud-based processes, services, applications, and data within or across organizations [9].

This research and development project focuses on a data system integration platform tailored for the construction phase, categorizing it as an iPaaS. Regarding with construction phase, several platforms have been proposed and are being implemented like Infrakit [10] in Finland and Landlog [11] in Japan. Infrakit is one of integration platforms for collaboration among stakeholders in construction phase. Using this feature, real-time quality control reporting in construction projects is being attempted [12]. Landlog is one of the integration platforms for utilizing construction management information from heavy machinery. This platform is developed by 4 companies including Komatsu [13] and provide various services for not only construction but also construction planning. Compared to these cases, this platform is designed as a versatile integration tool that allows for the flexible combination and utilization of devices and applications in accordance with on-site requirements.

3 Specifications for a data-system integration platform

3.1 Stakeholders of the platform

Table 1 delineates the attributes and specific examples of potential users. These users span a wide range, including clients, main contractors, subcontractors, and manufacturers, all of whom play integral roles in the construction process. Additionally, IT vendors, startups, and various manufacturers are identified as key stakeholders for the integration of existing applications and devices. To cater to the varied demands of these users, developers of new services, notably startups and construction firms engaged in technological innovations, are also considered vital stakeholders.

3.2 Characteristics of the construction phase and issues to be resolved

Table 2 outlines the unique characteristics and challenges of the construction phase. A notable feature of this phase is the variability of the supply chain across different sites. The inconsistency of the supply chain poses a challenge, as it is impractical for all suppliers to adopt a specific commercial system. Additionally, determining the essential functionalities within a single organization is complex, given that main contractors, subcontractors, leasing companies, manufacturers, and others must jointly consider and implement necessary features. To overcome these challenges, the system must possess extensibility, the capability to enhance functionalities based on each company's specific needs.

Table 1 User attributes and representative examples

Attributes	Specific examples
Users	clients, main contractors, sub-contractors, and manufacturers
Application developers	IT vendors and startups
Device developers	survey instrument manufacturers, heavy machinery manufacturers and IoT device manufacturers.
New service developers	startups and contractors

Table 2 Key characteristics and challenges in the construction phase

Characteristics	Issues
Supply chain varies by site	Issue 1: Difficult to use certain commercial systems Issue 2: Difficult to determine the functions required by one organization
Single item production and construction methods vary depending on site	Issue 3: A wide variety of required functions Issue 4: The developers can be diverse
Different sensing is required for each site	Issue 5: Necessary of data collection methods from devices

3.3 System architecture

To achieve extensibility, it is crucial to modularize functions and develop a system that allows for effortless replacement and API integration. To meet this criterion, the data-system integration platform utilizes a microservice architecture. Microservices are a distributed architecture comprising individual service components. In the context of the construction phase, as indicated as issue 3 and 4 in Tables 2, the required functionalities and their developers can vary significantly. It is impractical to incorporate all components as functions of the data system integration platform. Therefore, it becomes necessary to implement microservices that can effectively collaborate with external systems.

In considering the integration with external systems, the system configuration of the data-system integration platform is depicted in Figure 2. This diagram categorizes the system into three distinct layers: the platform layer, the analysis and processing service layer, and the construction management information collection service layer.

The analysis and processing service layer is designed to facilitate collaboration between web and desktop applications. In this layer, functionalities are represented as individual components. Meanwhile, the construction management information collection service layer is tailored for the interaction between survey instruments and internet of things (IoT) devices, with each device and instrument being depicted as a component.

The platform layer consists of the data system integration platform and an existing, previously developed platform. Within this layer, the data system integration platform is equipped with essential functions on a component basis.

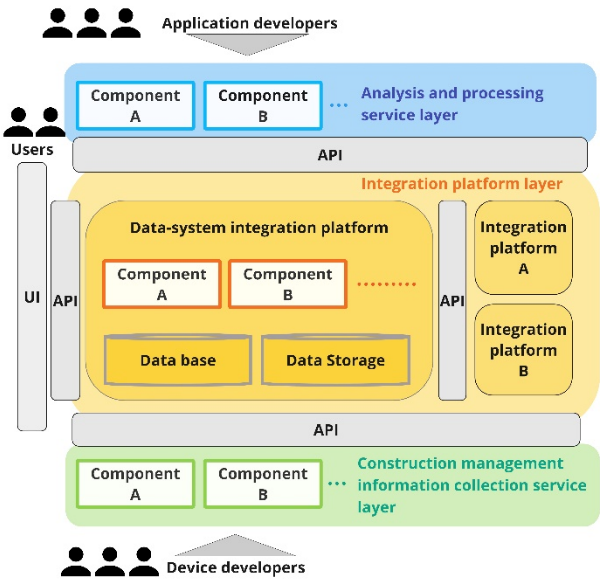

Figure 2. System configuration diagram of the data-system integration platform

4 Prototype development

4.1 Use case configuration

The prototype of the data system integration platform, targeting the construction stage, has been specifically developed for as-built inspections. This use case involves a range of users, including construction companies and their clients. To ensure the reliability of construction management information, the platform envisages API integration with a blockchain-based system [15]. Figure 3 illustrates the system usage flow when conducting as-built inspections of ICT earthwork and new Austrian tunneling method (NATM) construction.

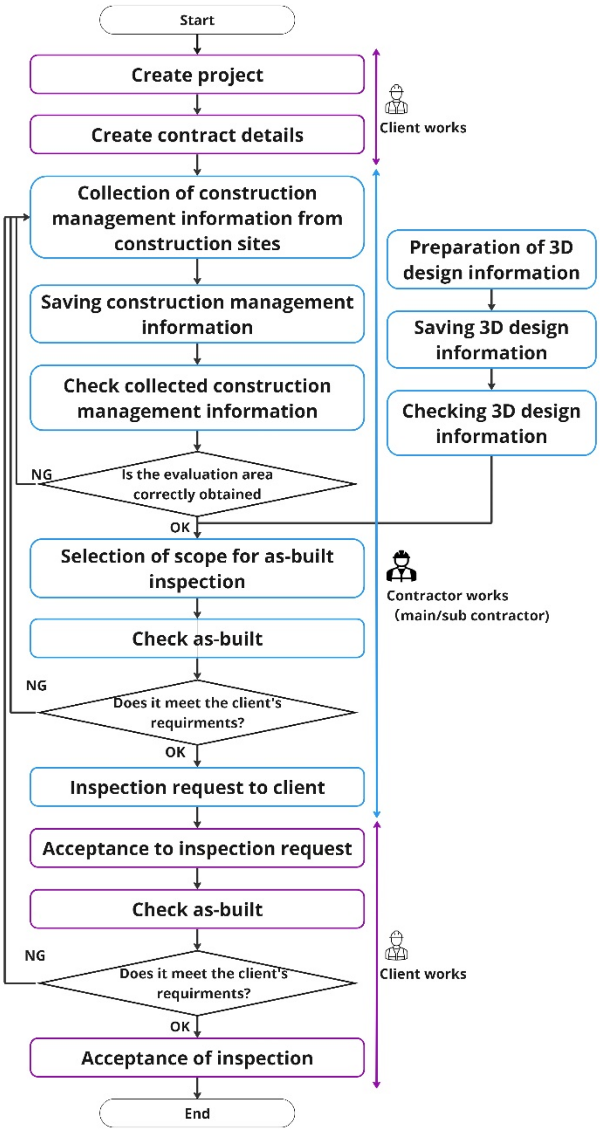

Figure 3. System usage workflow for as-built inspections

4.2 System requirements definition

In the process of defining system requirements, functionalities have been established to adequately address two key aspects: the capacity to perform as-built inspections and the ability to maintain system extensibility. Initially, for the development of a prototype capable of as-built inspections, functionalities such as visualization, analysis, and required APIs at each stage of the system usage flow were determined.

Table 3 enumerates the specific items targeted for visualization and analysis in the prototype, along with their respective formats. The visualization function encompasses essential features for verifying construction management, design, and as-built data. Additionally, for analysis purposes, features critical for determining the scope of the as-built inspection and for the evaluation of the as-built itself are included.

The focus of this study also encompasses the management of large-scale point-cloud data, which is essential for construction management information. Consequently, analysis functions such as trimming and noise removal of point clouds are necessary. The process of discrepancy calculation for as-built evaluations, involving comparisons between point-cloud data and 3D design information, varies depending on the construction type. For the trial, as information and communications technology (ICT) earthwork was the focal point, a specialized as-built earthwork evaluation function was developed. The evaluation parameters adhere to the standards set by Japan's Ministry of Land, Infrastructure, Transport, and Tourism.

Table 3 Visualization and analysis functions with corresponding file formats

Function	File formats
Visualization	
3D design information	IFC, LandXML, obj, stl
2D design information	dxf
Point cloud	las, csv, txt, xyz
As-built	csv
Alignment	csv
Analysis	
Trimming for point cloud	las, csv, txt, xyz
Noise removal for point cloud	las, csv, txt, xyz
As-built evaluation for ICT earthwork	Input: las, csv, txt, xyz Output: csv, json

To maintain system extensibility, APIs were integrated to enable interaction with external services. Table 4 outlines the service layers anticipated for integration and implementation within these APIs. In the integration with the analysis and processing service layer, APIs have been developed not only for uploading alignment and as-built information but also for retrieving various types of data necessary for analysis and processing. This allows external applications to extract data from the data-system integration platform and store their analysis results. In terms of integration with the construction management information collection service layer, APIs facilitate uploading of point clouds from survey instruments. Furthermore, if various data types include reference point coordinates, there is an API to update these coordinates. Given that diverse types of information are uploaded over the network, there exists a potential risk of upload failures. To address this, a file upload completion notification API has been implemented. This API can be accessed by an application or survey instrument upon successful data upload, providing a confirmation of the upload's completion.

Table 4 Service layers anticipated for integration and associated APIs

Service layer	Implemented APIs
Analysis and processing service layer	- API for uploading alignment information - API for uploading as-built information - API for file upload completion notification - API for getting alignment information file list - API for getting point cloud file list - API for getting design information list - API for downloading file
Construction management information collection service layer	- API for uploading large-scale point cloud upload - API for updating reference points of various files - API for file upload completion API

5 Trial and evaluation

5.1 Setting trial contents

The trial for this data-system integration platform was assessed from two main perspectives: "usefulness for the user" and "satisfaction of system characteristics". Consequently, two distinct trials were established: "Trial 1: Evaluation of Usefulness" and "Trial 2: Verification of System Characteristics", each aligning with the respective perspectives. These trials were conducted as part of the activities of a sub-working group (sub-WG) under a committee formed by the Japan Federation of Construction Contractors in 2022. The sub-WG saw participation from over 20 companies representing a diverse range of industry sectors, including main contractors, subcontractors, startups, IT vendors, manufacturers, and consultants. Trial 1 primarily involved main contractors and subcontractors, while startups and manufacturers were the focus of Trial 2.

5.2 Trial 1: Evaluation of usefulness

For the evaluation of usefulness, a questionnaire survey was administered following the testing of the prototype. This trial included ten contractors. Test data were specifically prepared to ensure that the evaluation results were not influenced by variances in construction management and 3D design information. Table 5 presents a summary of these trials.

The trial encompassed the contractor's implementation within the system usage flow (depicted in blue in Figure 3), while the client's implementation scope (indicated in purple in Figure 3) was executed by the study's authors. Figure 4 depicts an example of the results obtained by adhering to the system usage flow, illustrating as-built information in a color-coded format to highlight discrepancies between the design and actual construction. It is important to note that for the analysis of as-built evaluations, the use of external services was intentionally avoided to ensure uniform conditions among the participating companies. Instead, the analysis function integrated into the prototype was utilized.

Table 5 Overview of the trial process

Items	Content
Construction method	- ICT earthwork
Construction management information (Point cloud)	- File format: txt - Amount of data: 2,856 MB (2.9 GB)
3D design information	- File format: LandXML - Amount of data: 5 MB
Content of as-built evaluation information	- Average value - maximum and minimum value for discrepancy between design and actual - Evaluation area, - Number of evaluation point data - Number of rejected points

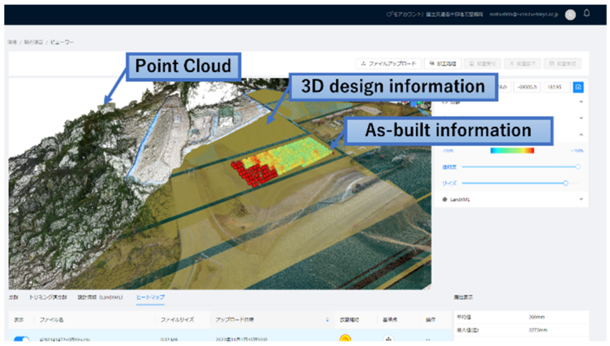

Figure 4. Illustrative case from the trial.

The evaluation of the trials was aligned with the standards outlined in ISO/IEC 25010 [16]. This framework defines the quality characteristics of software as evaluation metrics. The questionnaire items, derived from these standards, are compiled in Table 6. Notably, while operability and willingness to use are not specified as quality characteristics by the ISO, they were included as crucial aspects for assessing usefulness. Additionally, inquiries were made regarding the practicality and operability of each function, with the specifics of these functions detailed in Table 7.

A questionnaire was developed, employing a five-point scale for responses. A score of 5 represented the highest rating, while 1 was the lowest. The results, depicted in Figure 5, revealed that all users rated the effectiveness and efficiency as 5 and 4, respectively. This indicates a certain level of effectiveness and efficiency achieved for the users. In terms of practicality and operability, over 60% of users awarded high ratings for all items, with the exception of the analysis operability. Free responses concerning the operability of the analysis suggested improvements, such as the ability to specify the scope for as-built inspections using coordinate values. The practicality and operability ratings for each function, when compared to commercially available software, were likely influenced by factors such as the prototype's limited feature implementation, resulting in relatively lower ratings.

Table 6 Questionnaire items assessing software quality characteristics

quality characteristics		Questions
Effectiveness	-	Is it possible to achieve as-built inspection works by utilization of the system?
Efficiency	-	Does the use of the system make as-built inspection works more efficient?
Practicality	-	Do you think the features of visualization, analysis, and as-built information visualization are useful in as-built works?
Operability	-	Are the features of visualization, analysis, and as-built information visualization easy to operate?
Willingness to use	-	If the system is fully operational, would you like to implement it in your company's operations?

Table 7 Detailed descriptions of each system function.

Functions		Details
Visualization	-	Various visualization functions such as 3D design information and point cloud
Analysis	-	Trimming of point cloud
	-	Selection of scope for as-built inspection
	-	analytical functions for as-built evaluation
Visualization of as-built information	-	The visualization function of the analysis results (visualization of heat maps)
	-	The visualization function of as-built evaluation information

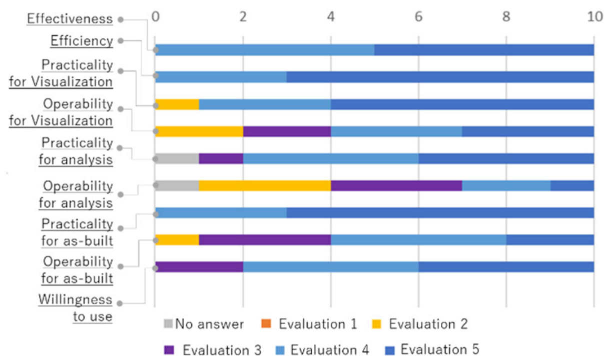

Figure 5. Questionnaire results analysis.

5.3 Trial 2: Verification of system characteristics

The system characteristic of extensibility was a crucial aspect to be verified in this study. To this end, 9 companies, including startups and IT vendors, participated in the verification process. The focus of this verification was on the integration capabilities of the data-system integration platform, specifically regarding the components of the analysis and processing service layer and the construction management information collection service layer.

The external services integrated for this verification included a desktop application with an as-built evaluation function, laser scanners, and mobile devices capable of collecting point cloud data as shown in table 8. Integration with these services was facilitated mainly using the API provided by the data-system integration platform.

A case study was conducted to demonstrate the practical application of this system in the as-built lining concrete evaluation for the NATM. The point clouds required for this evaluation were of shotcrete and lining concrete, with the objective to assess the inner width, height, and lining thickness by analyzing these point clouds. ENZAN's Application and iXs's device is utilized for this trial of NATM.

Table 8 Integrated applications and devices

Type	Developers and suppliers
Application	
As-built analysis for NATM	ENZAN [17]
As-built analysis for ICT earthwork	FUKUICOMPUTER, Inc. [18]
Structure from Motion/ Multi-View-Stereo (SfM/ MVS) analysis enfine	SkymatiX, Inc. [19]
Device	
Terrestrial laser scanner	iXs [20] [21]
Terrestrial laser scanner (Using Trimble Connect [22])	Nikon/Trimble CO., LTD. [23]
Lidar installed on mobile	OPTiM Corporation [24]
Unmanned aircraft vehicle (UAV)	Skydio [25]
Laser scanner equipped on heavy machinery	Fujita Corporation [26] Leica Geosystems [27]

The integration with the external analysis and processing service was accomplished through the available API, and the outcomes of the as-built evaluation for NATM are illustrated in Figure 6. The results show that the essential evaluation information could be effectively outputted, enabling a trouble-free as-built evaluation. The visualization, storage, and conversion functions, previously employed in ICT earthworks, were repurposed here. For visualization, additional line-drawing functions indicating the inner width and height were implemented, while the analysis function's as-built evaluation program was integrated with an external service. This trial successfully demonstrated the platform's capacity for functional expansion. Furthermore, the trial confirmed the feasibility of integrating the platform with various survey instruments and mobile device applications.

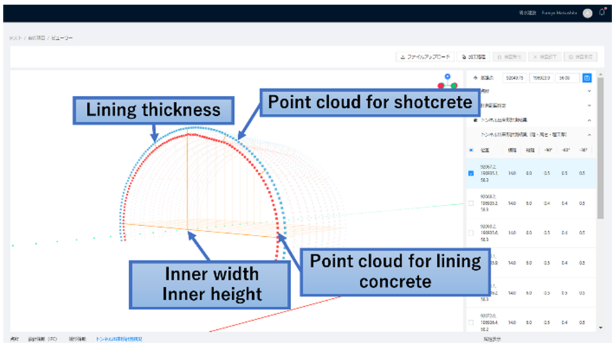

Figure 6. As-built evaluation example for the new Austrian tunneling method (NATM).

6 Conclusion

The aim of this study was to define the essential requirements for a data-system integration platform tailored to the construction phase. In pursuit of this objective, a prototype was developed, and its practicality assessed through various trials. Upon analyzing user needs, microservices were selected for their capacity to fulfill the system's extensibility requirement, facilitating integration with external services via APIs. This approach led to the development of a prototype, with trials focusing on ICT earthwork and NATM construction as practical use cases. The trials demonstrated that the system was highly effective and efficient in meeting user needs. The verification of system characteristics confirmed that extensibility, a key system attribute, was successfully achieved. In future studies, it will be essential to explore the platform's adaptability to a broader range of use cases. In addition, it is needed a comparative case study to highlight the advantages of the proposed platform over existing platforms. Furthermore, ongoing discussions with stakeholders involved in the platform's development and operation will be crucial for its readiness for broader practical implementation in construction projects.

7 Acknowledgment

This research was undertaken as part of the initiatives of School of Engineering, at the University of Tokyo, and the Sub-Working Group of the Committee formed by the Japan Construction Industry Federation. We received substantial support from numerous stakeholders for field trials and various other activities. We wish to extend our heartfelt gratitude for their invaluable contributions and assistance. In addition, in designing the system, we received advice from Mr. Tsujioka of Gartner Japan and Dr. Morita of the School of Engineering, at the University of Tokyo. We would like to express our gratitude to both of them as well.

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