BIM-Integration of Light Construction Equipment

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Abstract –

BIM (Building Information Modeling) has become increasingly important in recent years. At the center of BIM is the digital information model of a building. While such information models are already used intensively in building construction for small-scale robotic applications, digital models are only used for large-scale measures and machines in civil engineering. Light construction equipment has not yet been integrated into digital construction management in civil engineering despite its manifold potentials. This publication therefore takes a closer look at the integration of light construction equipment into BIM-supported digital civil engineering. For this purpose, the fundamentals and the state of the art are presented based on literature, and the linking of BIM and light construction equipment is conceptualized and validated by means of a compaction case study.

Keywords –

BIM; DTM; civil engineering; digital construction; light construction equipment; information models

1 Introduction

BIM (Building Information Modeling) has become increasingly important in recent years [1]. The digital model of a building is at the center of BIM. This contains both three-dimensional geometric information and non-geometrical information such as materials, costs, and technical properties, and is therefore characterized by a high level of information depth [2].

Due to this development, BIM is also increasingly entering the focus of construction equipment manufacturers. Construction equipment is to be integrated with BIM so that efficiency potentials can be exploited and new business models can be developed. This will enable construction equipment to be increasingly integrated into the construction value chain, reducing costs and increasing safety and efficiency [3].

While this integration is fully underway for newly developed construction robot concepts and heavy earth-moving machines (see section 2.2), light construction equipment distinguished by an operating weight of up to 1.5 metric tons [4,5], like compaction plates, walk-behind dumpsters, and trench rollers, is excluded from this development, leaving safety, efficiency, and cost reduction potentials undiscovered [6,7]. Therefore, the object of this paper is to *investigate BIM-integration of light construction equipment,* specifically by (2) depicting the current state of the art and requirements regarding BIM-integration of construction equipment, (3.1) examining the requirement gaps between heavy and light equipment integration, (3.2) introducing a conceptual framework for the integration and (4) conducting a compaction case study evaluating the framework.

2 State of the art

With ongoing digitalization efforts, the digital construction ecosystem is becoming more complex. It is therefore useful to depict task management before diving deeper into its components. Generally, tasks on a construction site pass three levels: project management, work instruction, and execution [8]. Depending on the type of construction (building or infrastructure), project management revolves around either a BIM (e. g. *.ifc) or digital terrain (e. g. Land*.xml) model that is enhanced through multiple dimensions (5D) and simulations [9]. Between project management and the actual execution on site, the respective information model must be transformed through a Construction Site Control System (CS²) in the work instruction level to form an executable task. The task is executed by semi-automated heavy equipment such as machine-controlled excavators or autonomous robots. Figure 1 depicts the digital task management on future construction sites.

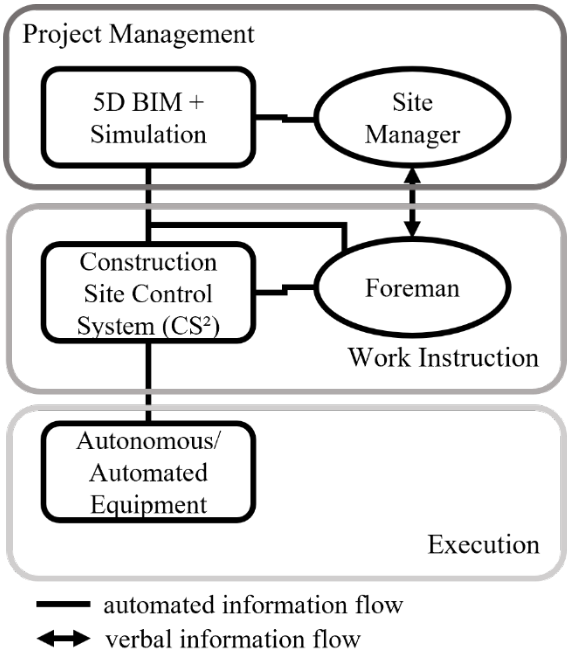


Figure 1: Task management ecosystem on construction sites [8]

A similar three-level structure is part of the ISO 15143-4, a norm under development focusing on topographical data exchange on mixed fleet worksites [10]. It standardizes the server-to-server data exchange between machine-specific Vendor Integration Systems (VIS), more commonly known as grade- or machine-control systems, and a general Site Management System (SMS) containing overall jobsite information and digital terrain models, as shown in Figure 2.

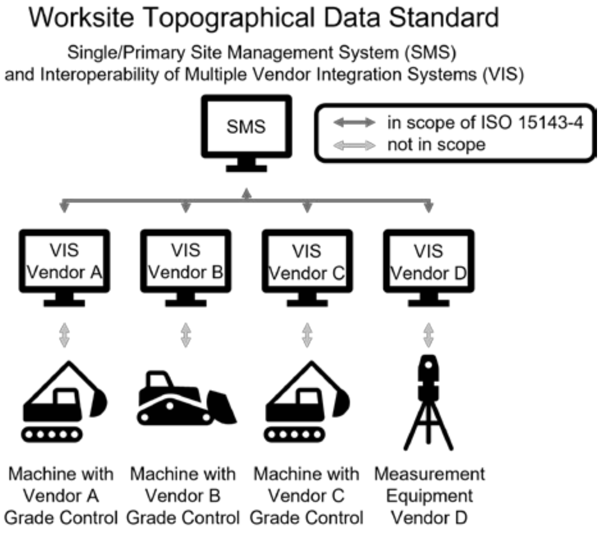


Figure 2: Structure of topographical data exchange on construction sites according to ISO 15143-4 [10]

According to expert interviews on “building information modeling (BIM) in construction equipment scheduling and equipment-heavy operations” [11] with six equipment management professionals, BIM managers, and construction equipment developers conducted by the authors, five requirements must be met in order to integrate construction equipment into the BIM methodology:

The equipment
- must be able to receive, transform, and transmit data, and
- must align itself and data collected during operations with the information model.

The information model
- must contain information necessary for the task to be executed by the equipment, and
- must provide a sufficient information structure to include received information in a meaningful way.

The task
- must be sufficiently specified in both the information model and the software of the equipment.

After this process-oriented digression, the next section depicts the technological fundamentals.

2.1 Fundamentals

In the context of this work, building information modeling (BIM) is defined as the “use of a shared digital representation of a built asset to facilitate design, construction, and operation processes to form a reliable basis for decisions” [12]. The afore-mentioned information models (*.ifc and Land*.xml) comply with this definition. A BIM-model is an object-oriented representation of a building, and a digital terrain model (DTM) is a digital representation by means of a point cloud and a polygon mesh of existing or planned topographies.

In order to interact with these digital representations, automated equipment and robots must be able to align themselves with the information model in the digital environment. Therefore, automated equipment in open-field infrastructure construction use positioning systems such as differential global navigation satellite system (DGNSS) or real-time kinematics (RTK) [13,14], while autonomous robots or more automated equipment in building construction use localization algorithms such as simultaneous localization and mapping (SLAM) [15,16] or ultra-wideband (UWB) [17].

Construction equipment can be classified by size or purpose. This paper focuses on light construction equipment (LE). Light refers to equipment with an operating weight of up to 1.5 metric tons. This includes mostly hand-held and non-ride-on equipment. Most of the newly developed construction robot concepts fall under this construction equipment segment.

2.2 State of research

The state of research covers two main areas of effort regarding BIM integration of construction equipment.

First, conventional heavy equipment is digitally enhanced to interact with information models.

Bouvet et al. [18] developed a real-time localization system for heavy compactors that maintains a positioning error lower than 0.2 m with a low-cost internal sensor set.

Heikkilä et al. [19] introduced eight modules to produce a fully autonomous compact excavator. These contain “open information modeling”, “positioning in accurate information system”, and “mission planning and work task creation” in regard to BIM-integration of construction equipment.

Yamamoto et al. [20] presented an autonomous hydraulic excavator that uses a simplified three-dimensional mesh of design data comparable to specific digital terrain models.

Halbach and Halme [21] developed 3D graphical job planning tools to support an autonomous wheel loader. Standard information models such as DTM or BIM are not supported by these tools.

Second, construction robotics researchers rely on information models for navigation and control purposes.

Follini et. al. combined the Robot Operating System (ROS) with BIM for applications in construction logistics [22], specifically for navigation and task planning. Automatic updating of the construction process in the *.ifc-file is a desired future development goal [23].

Xu et al. [24] evaluated Hilti’s Jaibot in a case study. The Jaibot collects design information from a modified BIM model. They found that characteristics of the information model (e. g., planning accuracy) influence the drilling performance.

Brosque et al. [25] compared manual and robotic concrete drilling for installation hangers. The deployed robot accesses BIM-models with a level of development (LOD) of 400 for design information.

Regarding light equipment, research projects and industrial applications are sparse. Light equipment vendors have upgraded sensor systems in recent years in order to obtain more data. An example is the coupling of telematics and compaction data, which allows the user to track the compaction progress in a web-application [26–28]. Since the obtained information is solely kept in the respective applications and cannot be aligned with an information model with a higher level of information or geometry, integration of light equipment and BIM is still missing.

3 BIM-Integration Concept

In order to counter the missing integration of light equipment and BIM, this chapter introduces a general BIM-integration concept in section 3.1. The concept is enhanced with light equipment specific requirements in section 3.2.

3.1 BIM-Integration of Light Equipment Concept

The concept for integrating BIM and construction equipment comprises five essential steps derived from the requirements mentioned in section 2 (see Figure 2).

1. First, the information necessary for the task must be included or generated in the information model. For this purpose, BIM or DTM software allows the user to check or edit the information model.
2. The information must then be exported from the information model, which can be done using the *.ifc or Land*.xml standard data formats. The data exported in this way should focus on data relevant to the construction equipment operation to keep data traffic low and must obey a predefined specification of the task so that the meaning of the data is conserved.
3. In order to work with the aforementioned information, the equipment must be technically able to receive and transmit information. Since light equipment moves freely and on different construction sites, a wireless network connection via tele- or radiocommunication is recommended.
4. Data transformation capabilities in the equipment ensure adequate interpretation of the received and the to-be transmitted data. In addition to this, light equipment must be able to align itself and to data generated in operation with the information model. Sensor systems along with localization and object detection algorithms provide this ability (see 2.1).
5. After transmitting data generated during operation from light equipment to the information model, it must be added to the information model for documentation or progress tracking purposes. In order to do so, the information model must follow an adequate information structure. BIM files in the *.ifc-format are object-oriented and allow information to be added to the respective objects. DTMs in the Land*.xml-format can either be updated (new file) or the information can be added to each geographical point. Another option for both information models is to include the information globally, e. g., in the file-header.

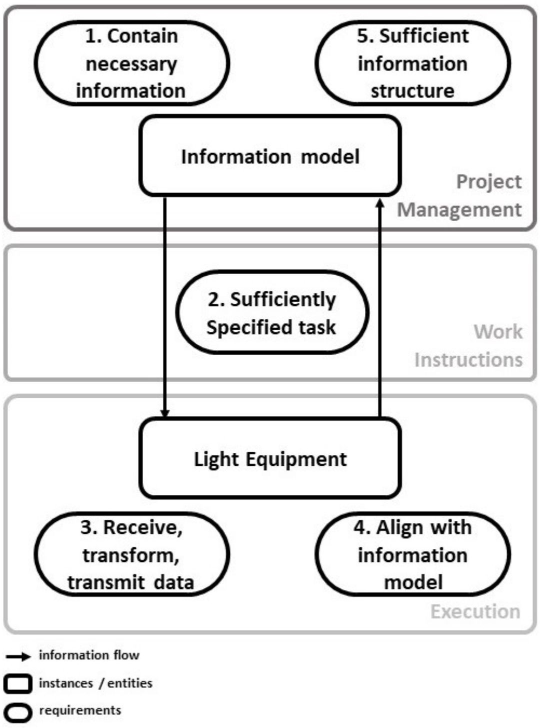


Figure 3: BIM-integration of light construction equipment concept

3.2 Light Equipment Requirements

Light equipment poses specific requirements for BIM integration. Since the mean price per machine in the light equipment segment is small compared to heavy equipment [29], expensive sensors increase the overall price. In order to keep a product compatible, sensor costs must be as low as possible.

Another characteristic of light equipment is its compact size and low operating weight. Therefore, the sensor system underlies strict space and weight limitations. All other requirements are similar to heavier equipment, e. g., robustness, easy commissioning, etc..

The presented concept for the integration of BIM and light construction equipment is evaluated in a compaction case study detailed in the next section. For better traceability, the respective numbers from chapter 3 are assigned to the individual steps below.

4 Case Study

To validate the concept described in section 3, the data exchange between an information model and a vibratory plate is implemented as an example. The objective is to specify a certain area to be compacted by the vibratory plate up to a certain compaction value with the help of an information model. This model combines the terrain information of a DTM with the property parameters of the work task in a BIM model. This information is used to carry out the compaction with the vibratory plate and transmit information about the degree of compaction back to the BIM model.

4.1 Setup

The test area consists of a ballast bed framed by concrete blocks in which the vibratory plate can move freely.

The vibratory plate is transformed into a cyber-physical system that can process, acquire and document data using the hardware components shown in Figure 3, and the Robot Operating System (ROS) version 2 [30].

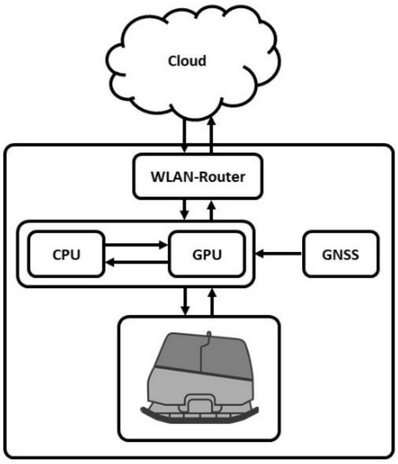


Figure 4: Hardware structure of the light equipment

A Central Processing Unit (CPU) and a Graphics Processing Unit (GPU) extend the vibratory plate via a machine interface, in order to be able to process the required information.

In addition, a GNSS module generates data for global localization. Since the accuracy of the GNSS position depends on external influences, position determination can be improved with DGNSS (meter accuracy) or Real Time Kinematics (RTK) (centimeter accuracy) [31]. This involves using a base station to provide correction data that attenuates the environmental influences on the GNSS position (see Fig. 4). The correction data can be obtained from a service provider as well, but this does not offer the same level of accuracy as a base station. In this study, RTK delivers positioning data with a mean accuracy of 1.5 to 3.0 cm.

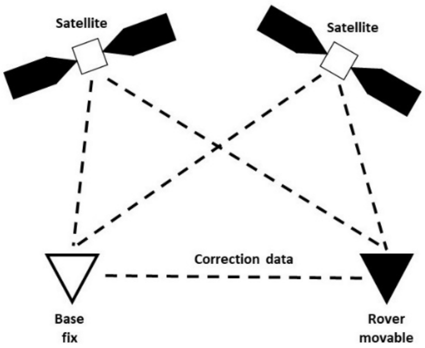


Figure 5: DGNSS and RTK concept

Via a WLAN interface and a router, the vibratory plate communicates with an external computing unit.

4.2 Setup and Execution

In accordance with Figure 2, Figure 6 shows the five necessary steps for the BIM-integration of light equipment. The information flows include the deployed data formats. The individual steps are described in detail below.

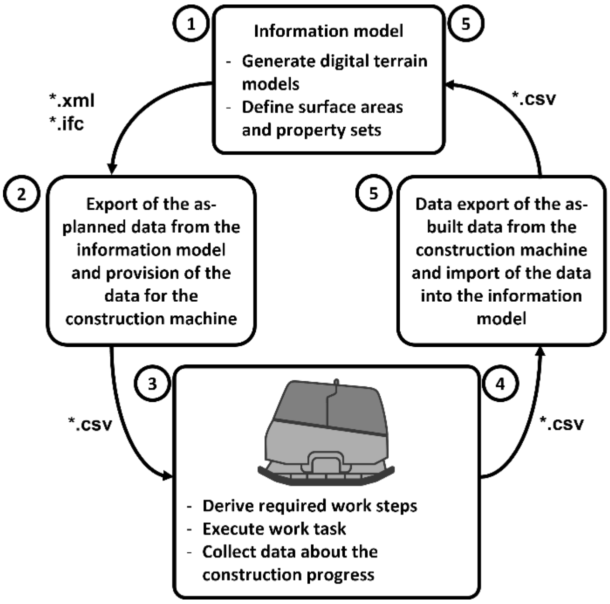


Figure 6: Overview Case Study Operation Setup

1. The first step in the realization of the case study was to create a digital terrain model of the construction area with the test area in (blue circle – see Fig. 7).
   This was done using the Autodesk Infrastructure and Civil 3D applications, which were used to generate the DTM from a point cloud.

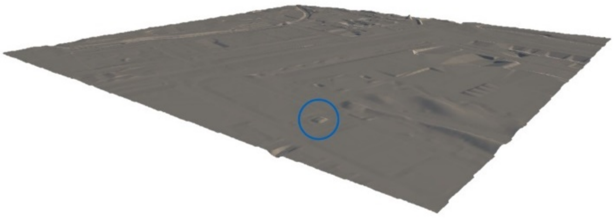


Figure 7: Digital terrain model of the construction site

Subsequently, a coordinate-based surface was defined in Civil 3D, to which a compaction value was assigned. The resulting surface is shown in Figure 7, where a bird's eye view of the construction site gives an overview of the entire test area.

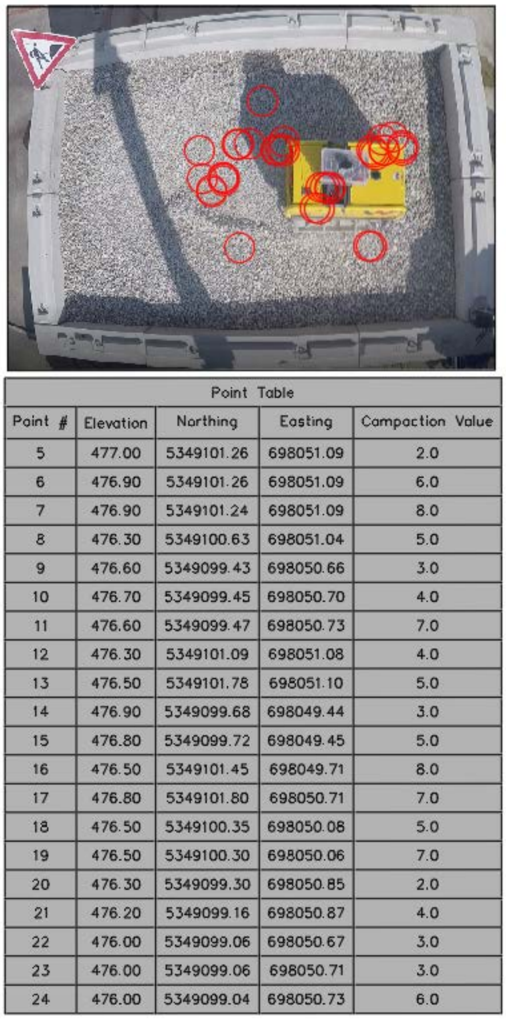
Compaction Value
Compaction Value 6

Figure 8: Digital terrain model with compaction factor as input

2. The data generated in this way was exported from Civil 3D using the *.ifc data format. The file obtained in this way was limited to the relevant information and converted into a data format that is readable by the machine. For this purpose, a python script was used. The resulting *.csv-file was then transferred to the vibratory plate.
3. As described in chapter 4.1, the vibratory plate is

able to process and use the information and to move independently. By measuring the superstructure acceleration of the vibrating plate, conclusions about the current compaction state can be drawn.

4. Based on these measurements, the vibratory plate executed the given work task. During execution, the compaction value was obtained locally by the vibratory plate. Matched with the GNSS position, the compaction value is stored locally in a documentation *.csv-file, which has the structure of a point cloud.
5. This file was then transmitted by the vibratory plate and imported directly back into Civil 3D. The result of the import, individual compaction points and the associated compaction values is shown in Fig. 8. The scattering of the compaction values is due to the incompatible soil used in the test bed.



Point Table				
Point #	Elevation	Northing	Easting	Compaction Value
5	477.00	5349101.26	698051.09	2.0
6	476.90	5349101.26	698051.09	6.0
7	476.90	5349101.24	698051.09	8.0
8	476.30	5349100.63	698051.04	5.0
9	476.60	5349099.43	698050.66	3.0
10	476.70	5349099.45	698050.70	4.0
11	476.60	5349099.47	698050.73	7.0
12	476.30	5349101.09	698051.08	4.0
13	476.50	5349101.78	698051.10	5.0
14	476.90	5349099.68	698049.44	3.0
15	476.80	5349099.72	698049.45	5.0
16	476.50	5349101.45	698049.71	8.0
17	476.80	5349101.80	698050.71	7.0
18	476.50	5349100.35	698050.08	5.0
19	476.50	5349100.30	698050.06	7.0
20	476.30	5349099.30	698050.85	2.0
21	476.20	5349099.16	698050.87	4.0
22	476.00	5349099.06	698050.67	3.0
23	476.00	5349099.06	698050.71	3.0
24	476.00	5349099.04	698050.73	6.0

Figure 8: Data points with position and compaction factor as output

4.3 Evaluation of requirements specific to light equipment

The light equipment specific requirements mentioned in section 3.2 of robustness, easy commissioning, light weight, low cost, and compact size are evaluated for the case study. Table 1 shows an overview of all necessary additional components. The requirements of robustness and easy commissioning are fulfilled by these components for a prototyping/concept purpose, but could be improved in future works or in mass-production. Weight is negligible in the case of a vibratory plate (793 kg) due to the high weight of the base plate. The hardware system needed for the mentioned functionality has a total cost of less than 600 € (566,90 €) and requires a space of roughly 300 x 200 x 100 mm. The major cost drivers are the two needed development boards, which are RTK capable GNSS receivers.

Table 1. Hardware components size and cost

Component	Size [mm]	Cost [€]
CPU + GPU	85 x 56 x 16	77,90
Router	144 x 230 x 37	33
2 x RTK/GNSS receiver	110 x 55	456 (228 each)

The cost and size of the integration is small relative to the vibratory plate’s dimensions (1.183 x 870 x 830 mm) and market price (10,000 €). Therefore, the requirements of low cost and compact size are met in this case study.

5 Conclusion

The paper at hand investigates BIM-integration of light construction equipment. Therefore, the state of the art and requirements of BIM-integration of construction equipment is depicted. With light equipment specific requirements in mind, an integration concept is introduced. Finally, the concept is successfully validated in a compaction case study.

The case study revealed that an integration of light equipment and BIM methodology can comply with the requirements in practice. Since the case study required adaptions to the information model and light equipment as well as introduction of a standardized task description, future research should focus on the introduction of transparent interfaces between the information model and light equipment, as well as standardized task descriptions. The ISO 15143-4 standard for the exchange of worksite topographical data, which is currently under development, could prove to be an adequate starting point [10]. The industry should evaluate serial development of the solution to become part of mass-produced light construction equipment.

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