Enrichment of an IFC model with Information from tracked building inspection

Christian Kreyenschmidt, christian.kreyenschmidt@jade-hs.de
Institute for Database-oriented Engineering, Jade University of Applied Sciences, Oldenburg, Germany

Bernd Hobbie, bernd.hobbie@jade-hs.de
Institute for Database-oriented Engineering, Jade University of Applied Sciences, Oldenburg, Germany

Sebastian Hollermann, sebastian.hollermann@jade-hs.de
Institute for Database-oriented Engineering, Jade University of Applied Sciences, Oldenburg, Germany

Jakob Beetz, j.beetz@caad.arch.rwth-aachen.de
Department of Computer Aided Design, RWTH Aachen University, Aachen, Germany

Abstract
This paper describes the enrichment of a building information model (BIM) with information from a building inspection or a motion path and the characteristics taken up thereby, for example pictures, comments or similar. The data from the motion path is generated with an autonomous Indoor Position System (IPS) and superimposed with an Industrial Foundation Class (IFC) model. The superimposition of the information like images with the IFC model is then assigned through collision detection of the tracked motion path and the spaces in the IFC model. It is also discussed how deviations of long motion paths can be compensated. The presented solution offers an open BIM approach for a robust and efficient data overlay. This approach could also be used for a real-time localization or Simultaneous Localization and Mapping (SLAM).

Keywords: IPS, BIM, SLAM, information enrichment, tracking

1 Introduction

1.1 Motivation

The indoor positioning of pedestrian and Points of Information (POI) in a building is getting more and more important for a lot of applications. While outdoor positioning and localization are well established caused by Global Navigation Satellite System (GNSS), the tracking inside a building is not possible because of the isolation of the signal from the satellite (Real Ehrlich and Blankenbach 2019). The applications for Indoor Position System (IPS) on a construction site are ranged from tool-, material-, labor tracking to robot tracking and some applications in the field of facility management. A typical use case for IPS in construction management is the documentation process of construction activities and anomalies.

The scope of this work is the information enrichment of a Building information model (BIM) by information like images and comments. These information are recorded in a building walkthrough with an IPS. Currently, this information is often located manually by note room numbers or scanning reference sources such as QR codes. Even for the site engineer's it is hard to describe the orientation of the information in the building. Especially in the shell construction state there are few orientation points to reference the information of an inspection. There are some well-known software solutions that solve this challenge of information tracking with augmented reality, but this seems not to be a robust and cheap solution for the mass market. Another quite new solution is the involvement of robots (Fabian Kurmann 2021) to ensure an automatically documentation process during the construction phase. Such robots walk through a specified path and scan the area with 360° images, points clouds or similar. The recorded anomalies must be evaluated by the site engineer afterwards. The method introduced in this paper is aimed at all parties involved in the construction process who need to locate building information in a building. This paper shows a solution to make this documentation process cost-effective, robust, as well as easy to use. This is important to make the application useable for small and middle-sized enterprises (SME) and raise the awareness of its useability for building inspection, an acceptance report or another use cases in the Architectural, Engineering and Construction (AEC) industry.

1.2 State of the art in IPS

For the development of IPS in the recent years a number of research reviews and summaries have been published that represent the current state of the art very well (Kunhoth et al. 2020) (Sakpere et al. 2017) (Brand et al. 2017). This paper is not primarily concerned with a contribution of improving indoor mapping, but rather with its application in an AEC use case. In the following section, a common overview of the current state of the art is shown.
Due to the development in this field, there are currently several options for indoor localization and navigation. As shown in Figure 1, Indoor positioning systems are based on different signaling technologies, for example, radio frequency identification (RFID), radio-based wireless local area networks (WLAN), ultra-wideband (UWB), infrared (IR), ultrasound, mechanical systems as used in this paper or images recognition (vision-based systems).

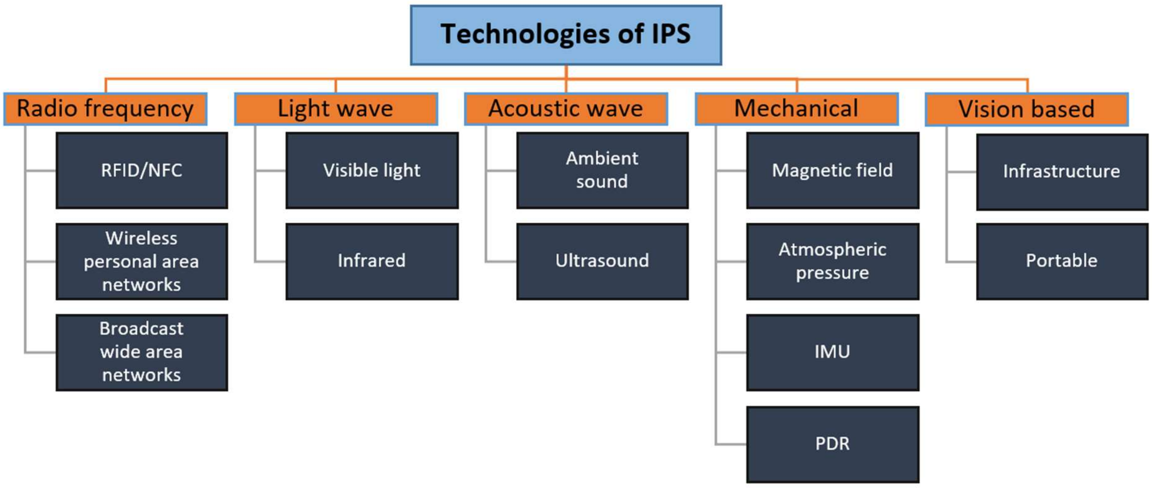

Figure 1. Major technologies in IPS, (see (Simões et al. 2020); (Subedi and Pyun 2020))

Modern stationary laser scanners are equipped with corresponding Simultaneous Localization and Mapping (SLAM) features and automate the localization of the scanned point clouds (Biasion et al 2019). Because of multiple sensors, this total station has a very high accuracy in indoor navigation. At present, the accuracy for wearable IPS is in the range of a few meters (1-3 m), so that accurate room navigation is possible. A robust and reliable IPS consists of a fusion of different technologies (Hybrid IPS technologies). These hybrid IPS combines two or more systems to improve the performance of each system.

1.3 IPS solution with IMU-Sensor and PDR

The autonomous system used in this paper is developed by *inertial elements*[1]. The choice of tracking technology was primarily based on applicability, cost, and usability. The motion sensor

[1] https://inertialelements.com/

consists of a shoe mounted inertial measurement unit (IMU) and a pedestrian dead reckoning (PDR) system for real-time indoor localization in an environment without GPS reception. The IMU shoe mount was also supplied by GT Silicon Pvt Ltd. Displacement and direction of the IMU is transmitted to a smartphone application and transmits data from sensors including i.e. accelerometers and gyroscopes in step frequency, which is typically 1 Hz for normal walking. Therefore, the low frequency PDR data (typically a few dozen bytes per second) also reduces the probability of transmission loss. This also relieves the computational load on the application platform.
The IMU sensor used is the Osmium MIMU22BLP in combination with the Android application DaReX as the interface, as shown in Figure 2a. The Figure 2b illustrates how DaReX detects the steps of its wearer and sets displacement and direction of each detected step in relation to the previous step and transmits the information as tracking points through the Bluetooth interface. The IMU can also be controlled via an application programming interface (API).

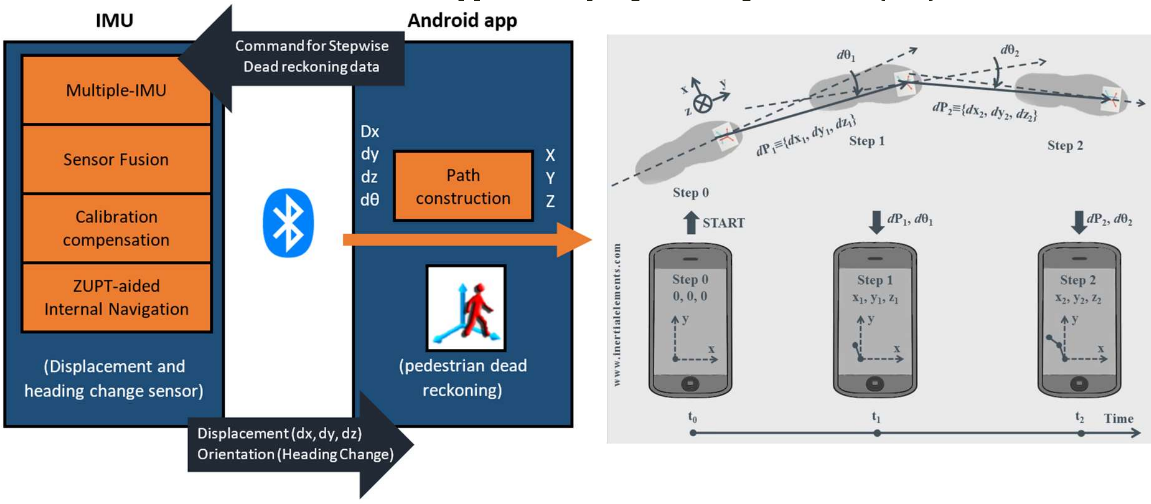

Figure 2. 2a: Interface IMU to PDR; 2b: The PDR System (see (Gupta et al. 2015)

The findings in this area of research shows that a lot of resources are being invested in the development of IPS with smartphones. Focused is the development of a standard that does not require any additional sensors or stational hardware except of the smartphone. The interest is an robust and affordable IPS for the mass market (Nguyen et al. 2021). In recent years, many research papers have been published that permanently improve the accuracy and simplicity of IPS. The technology has various application fields, from construction process to operation and maintenance in smart building. The improvement of a smartphone based autonomous IPS that uses machine learning to minimize their measurement errors has the potential to become a standard in the coming years (Chen et al. 2020).

2 Conceptual Approach

The concept of this paper is the superimposition of information such as images or tags to the related rooms using an IFC space model. Theoretically, superimposing with any volume space model would also be possible.
Figure 3 shows a schematic of the whole process, form motion path creation, information recording, information transfer and the superimposition with the IFC space model. After recording the motion path and the related tags, the information will be transferred to a database. This is done as an export or by synchronization from a cloud. From the database, the tracked motion path will be imported into an IFC viewer. Afterwards the recorded tags and the related motion path will be superimposed with the IFC space model to enrich the model information.

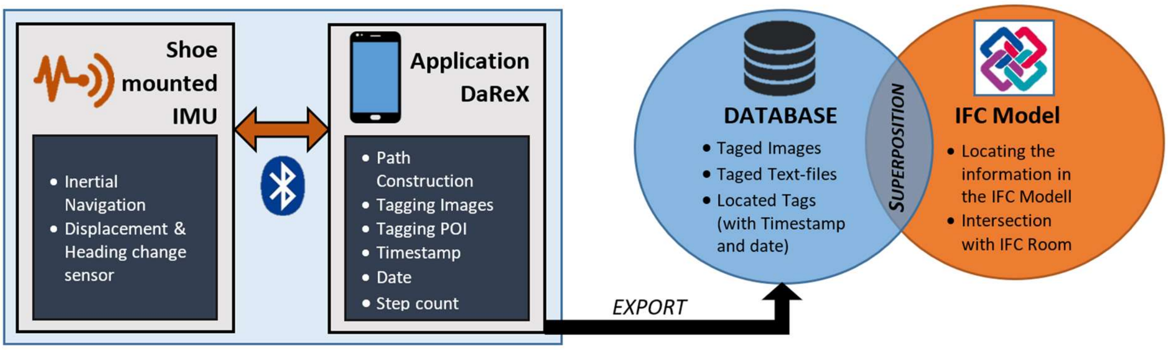

Figure 3. Schema Information to IPS

The superimposition between the information and the IFC space model is done after the test walk. Theoretically a simultaneous superimposition on a mobile device is possible and is discussed in Section 4.

3 Methodology

3.1 Tracking of the motion path

For the evaluation of the accuracy and handling of the IPS a total of 16 test tracks were recorded during this study. The total measured distance was about 4332m with 43 points of information and 96 reference points. The test track for the example field experiment described here has a length of 158m (filename: Test_Track_121115.log). The track crossed four rooms on the second floor of the Jade University of Applied Sciences in Oldenburg. The mounted system is shown in Figure 4(left). Every time the device is activated it needs to be calibrated. For the calibration the device needs to be moved in the figure of an eight several times[2]. The coupling of the navigation with the smartphone allows the recording of image and alphanumeric data in tags. By starting the record every motion is tracked. However, the tracking itself is not free of errors and you should act normal, that means avoid unnecessary rotations or abrupt motions. In the experiment described here we had some trouble with the drift of the system, this will be discussed in section 4. For the workflow and the later superimposition of tracked motion path with the IFC model, a reference point is necessary to align the IFC model and the tracked path . The alignment will be discussed further in section 3.2.

TIME STAMP	STEP COUNT	X	Y	Z	Distance	degree	TagName
10:10:39	1	2,53	2,34	0	3,46	288	
10:10:41	2	3,17	3,4	0	4,69	301	Spalling
10:10:42	3	3,63	4,55	0	5,92	307	
10:10:43	4	4,3	5,52	0	7,1	293	
10:10:45	5	4,84	6,54	0	8,26	306	
10:10:46	6	5,59	7,37	0	9,38	314	
10:10:48	7	5,71	7,33	0	9,5	332	
10:11:07	8	4,86	7,04	0	10,41	140	
10:11:09	9	4,37	5,87	0	11,68	158	Crack
10:11:10	10	3,7	4,77	0	12,97	167	
10:11:11	11	3,17	3,61	0	14,24	162	
10:11:12	12	2,62	2,42	0	15,56	137	
10:11:14	13	1,95	1,33	0	16,83	149	
10:11:15	14	1,31	0,2	0	18,13	157	
10:11:18	15	0,11	-2,09	0	20,72	166	
10:11:22	16	0,55	-5,56	0	24,21	79	
10:11:23	17	0,77	-5,89	0	24,61	144	
10:11:35	18	0,66	-5,35	0	25,17	253	Damage
10:11:39	19	-2,35	-4,11	0	28,43	228	
10:11:40	20	-2,89	-3,79	0	29,05	199	
10:11:56	21	-2,2	-4,51	0	30,05	63	

Figure 4. left: Shoe mounted IMU; right: Output as text document

The application on the mobile device generates a text-based log file from the walk-through. This was synchronized with a cloud database. An example of the data file is shown in Figure 4(right). The first table column lists a timestamp indicating the exact time per detected step, which is recorded in the second column. The columns X, Y, Z, distance and degree describe the motion path

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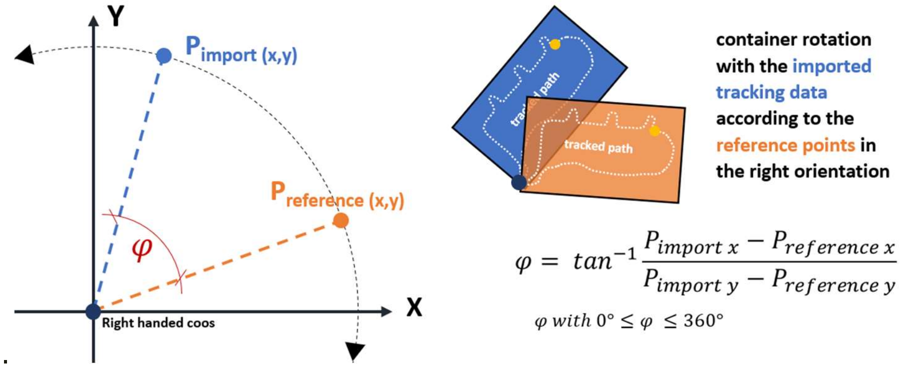
[2] https://inertialelements.com/support.html

and the measurement of the walk. This can also be viewed directly in the application. The last column shows the so-called TagName. Here, the point of information (POI) is marked, which means notes of individual measuring points are listed. The application of the mobile device allows directly taken photos, a text input, or a voice message of a specific POI. Afterwards, the POI is listed in the dataset with time, and location from the starting point. Each time a new inspection is recorded, a new log file is created.

3.2 Import and alignment of the model

The recorded motion path dataset is imported into the IFC Viewer Desite md[3]. The viewer does not have the direct possibility to import the tracked data from the log file into the program. The points were loaded into the project by accessing the application programming interface (API). For this purpose, an algorithm was created in JavaScript (ecma2009)[4], which loads the points to an information container that was created in the project of the IFC viewer. All points are contained within one container. This allows translations and rotations of the objects in a related set. Objects from the tracked motion path are loaded into the model and aligned according to the georeferenced coordinate system of the IFC model. The container still has to be rotated to the correct rotation and transformed to the right starting point of the tracked path. Four points of information (POI) and one reference point were created on the test path (Figure 6).



$$\varphi = tan^{-1}\frac{P_{import\ x} - P_{reference\ x}}{P_{import\ y} - P_{reference\ y}}$$

$$\varphi \ with\ 0° \leq \varphi \leq 360°$$

Figure 5. Rotation to the reference points

The reference point in Figure 6 is used to calculate the rotation angle of the container in the model as shown in Figure 5. This alignment process is implemented in JavaScript and is done automatically when the data is imported to the project container. Each of the 102 tracking points are included as objects, which allows the attribution of each object. That allows further information enrichment in the model. The full process including the script has been published in a Github repository[5].

[3] https://thinkproject.com/products/desite-bim/

[4] https://www.ecma-international.org/publications-and-standards/standards/ecma-262/

[5] https://github.com/hobbie-jade-hs/desite-indoor-navigation

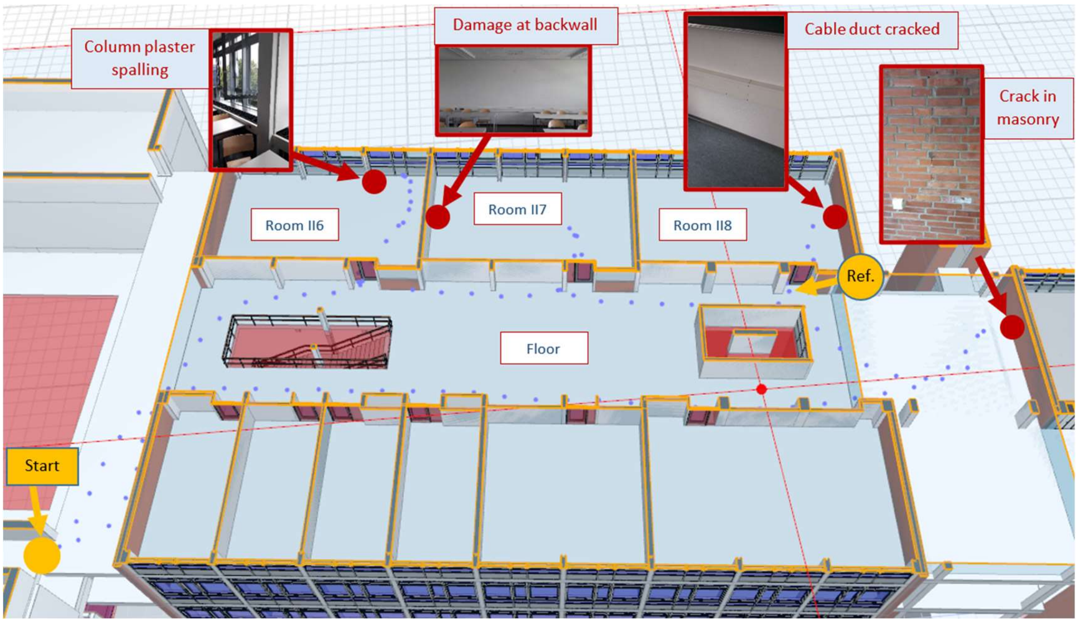


Figure 6. Test motion path and POI

3.3 Superimpose Information and IFC Model

After the tracked points are imported into the IFC viewer, the tags must be superimposed onto the IFC model. The IFC Viewer offers the possibility to superimpose objects with other objects by collision detection. We use this functionality to assign the information of the corresponding room number/-name. Another possibility is to superimpose between the TimeStamp and the external information such as images and comments. Now, the information or the tag is extended by the attribute of the room name/ room number.

Name	cp:ID	cp:Name	TimeStamp	TagN	Room [-]
Default (1)	02.11.2020_Hau...	Default			
TrackingPoint-11	c9802d08-6abf-...	TrackingPoint-11	12:11:29.824		II41
TrackingPoint-12	7277d236-a50b-...	TrackingPoint-12	12:11:31.037		II41
TrackingPoint-13	5bd57bb1-b759...	TrackingPoint-13	12:11:32.262		II41
TrackingPoint-14	3495086c-fae2-...	TrackingPoint-14	12:11:33.583		II41
TrackingPoint-15	75731f47-580d-...	TrackingPoint-15	12:11:34.792		II6
TrackingPoint-16	c40162c4-f35e-...	TrackingPoint-16	12:11:35.723		II6
TrackingPoint-17	36146343-a417-...	TrackingPoint-17	12:11:38.795		II6
TrackingPoint-18	13bb0ad1-ef4c-...	TrackingPoint-18	12:11:41.529		II6

Figure 7. Room mapping of the tracking points

The superimposition is based on the IFC Space entities of IFC, therefore it is unnecessary to have a complete building-model. Rooms and individual reference points are sufficient for superimposition. That means, this application use case could be transferred to the field of existing buildings or heritage BIM, whereas known IFC models are not so common. Moreover, this application use case can be taking place in the field of facility management.

4 Discussion and future work

4.1 IPS accuracy for long motion path tracking

Even if the accuracy of the IPS system is not the primary goal of this paper, 6 test tracks with longer distances (longer than 200m) were taken during the research work. The accuracy of the test motion path, shown in Figure 4, from start to end was accurate to within one meter and is sufficient for the application presented in this paper. Longer test distances showed bigger deviations. While the distance tracking and the recorded step frequencies of the walk resulted in less than 2.0m on a track length of 282.5m, constant rotations due to staircases led into a directional drift. The longer test motion path's (1-3) were over two floors (Δz=8.13m) and in this course the IPS was rotated 6 times by 360° (2.160°). The results of the measurement gap are shown in Table 1.

Table 1. Measurement gap of longer motion path tracking[6]

Tracknumber	Δx [m]	Δy [m]	Δz [m]	distance [m]	Δabsolut [m]
1. LOG_FILE_145833	-18,82	-14,51	-0,03	284,13	23,76
2. LOG_FILE_150723	-18,57	-12,75	-0,06	282,41	22,53
3. LOG_FILE_151551	-17,45	-8,18	-0,02	281,83	19,27
4. LOG_FILE_151246	-27,35	-5,73	-0,03	404,34	27,94
5. LOG_FILE_ 105405	-1,03	4,35	-0,08	272,52	4,47
6. LOG_FILE_ 110013	-1,24	-1,28	0,71	231,28	1,92

The distance of 404m, track 4 in table 1, refers to a track with complete 8 rotations by 360° (2,880°). The Tracks 5 and 6 were made by a walk through a construction site demolition with less than 720° rotation.

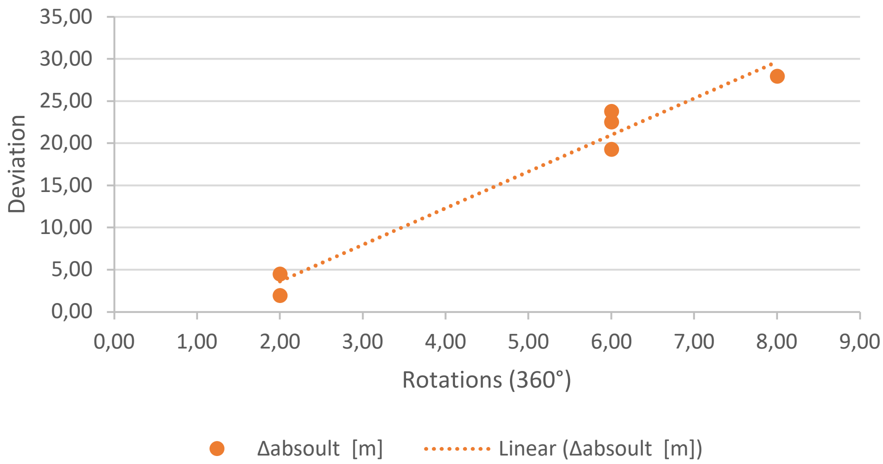


Figure 8. Deviation in the dependence on the rotation

The results in Figure 8 of the measurement gap shows the accuracy is decreasing with more rotation. The introduction of more measuring points or reference points could probably reduce the drift. This would require dividing the test track into small sections from one reference point to the next. Therefore, the different sections could rotate to the correct position as shown in the test in Figure 6.

4.2 Theoretical application as SLAM

The IPS and the PDR built an autonomous system that can create live localization in an unknown environment. With the use of a mobile device within a direct link to the IFC model, the user can see his location in the building. This is possible in real time and without an internet connection, which could be very suitable for construction site documentation in the shell state. This use case of Simultaneous Localization and Mapping (SLAM) is the subject of further research. Because of the on-going cooperation between a network of SMEs with the Jade University of Applied Sciences, this form of localization can be further tested in field studies.

4.3 Application for monitoring

A more advanced use case for the location of Points of Information in quality management and building inspection is the monitoring of existing anomalies and damages. A great enrichment of

[6] compare: https://github.com/hobbie-jade-hs/desite-indoor-navigation

automation in this field would be the exact positioning, for example to compare images of a damage from a specific point of view over a defined period. For digital image correlation (DIC) it requires the precise position of the viewpoint to the Point of Information (POI). The information might be included in the IFC model in the same way as described in the previous sections. Because the analysis of DIC evaluations of POI also depends on additional parameters such as camera, light, and other reference points, this use case remains to be explored.

5 Conclusion

The approach presented in this paper to integrate information and data from a tracked building inspection into an IFC model has shown the requirement and the setup for such an implementation and already contributes to data security and automation in the field of space accurate building documentation.
Even without the superimposition in a IFC model, the documented data during each walk-through means a high information value in the construction documentation: The data from the motion paths can be verified, validated, and evaluated before being transferred to an IFC model or another database. This creates a data pool with a very high value to project execution, improvement process and especially operation, because of the possibility to evaluate data from the construction process on specific areas.
Even if localization methods are described as autonomous and accurate today, the handling and setup of a corresponding workflow is not easy enough to establish them in the mass market. The challenge to the robustness of such a system is currently not given to generate a plug and play solution. The potentials and requirements presented in this paper illustrate how an IPS can make the construction and inspection process more transparent and leaner, with structured Points of Information that are located with an IPS. The wide range of development makes it difficult to predict which method will become widely accepted, or whether there will be a variety of best practice methods in the market.
The IMU sensor in combination with DaReX is confirmed to be useful for tracking applications in the AEC industry. The improvement of Indoor positioning systems is to expect. Nevertheless, it is necessary to increase the robustness of the solution presented here and to take up the discussed approaches in future research to produce more reliable tracking data for longer distances. A robust IPS with information transfer to open standards such as IFC will lead to more efficiency in the construction and operation of buildings.

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