An investigation into the impact of the Scan-to-BIM method on the design and construction of technical building services

Nijanthan Mohan[1], Michelle Ulbrich[1], Stefanie Bongard[1] and Rolf Gross[1]

Smart Building Engineering, Department of Civil Engineering, Aachen University of Applied Sciences, Bayernallee 9, 52066 Aachen, Germany

Abstract: The evolution of computers and information technology led to a digital revolution in the Architecture, Engineering and Construction (AEC) industry, which gave rise to the Building Information Modelling (BIM) technique. BIM is a process that generates and manages digital representations of buildings in terms of both physical and functional characteristics. Scan-to-BIM is a method for creating a 3D-building model based on point cloud data taken by a laser scan, which can be used for the different BIM-compliant design and construction processes. In this context, this research paper aims to investigate the impact of the Scan-to-BIM method on operations in the design and construction of Heating, Ventilation and Air Conditioning (HVAC) systems. To achieve this, a market study was made on the predominately used 3D laser scanners and point cloud processing software in Germany. For the processes in the design phase of HVAC systems, energy analysis of existing buildings involving heat load calculation according to DIN EN 12831 standard and energy balance according to DIN V 18599 standard was selected, analysed and evaluated. The software tool liNear from the liNear company for construction design and the ETU-Planer from the Hottgenroth AG were used for energy calculations. Adhering to the construction phase, a study was made to analyse the impact of digital twins and point clouds for construction progress inspection in the field of building services.

Keywords: BIM, Laser scanning, Digital twins, Construction progress control

1 Introduction and Aim

The construction industry is lagging in digitisation compared to other sectors. This is due to, on the one hand, the lack of willingness to introduce new planning methods and, on the other hand, the lack of expertise in this area. However, for years, digital tools and working techniques have been developed for the construction industry. One important method for digitising the construction industry is Building Information Modelling (BIM). BIM is a process for integrating information and technology to create a digital representation of a project. BIM brings together data from various sources and evolves in parallell with the actual project through its entire life cycle, including planning, construction, and facility management. It is a way of optimising planning and action in the construction industry and networks the various trades with each other to improve cooperation between the different specialist planners. The path from the drawing board and two-dimensional planning to three-dimensional planning is also inherent in using the BIM method. The digitalisation of essential processes in the entire life cycle of a building, from planning to the construction phase to operation, is intended to optimise processes and increase efficiency [1], [2]. In this context, this paper is aimed to analyse the impact of the scan-to-BIM process on the design and construction of technical building services. The study was commenced with a market study to identify the available hardware for laser scanning and was followed by expert interviews with construction managers in the field of technical building services to get an insight into current practices and expectations of the scan-to-BIM process. With this background, different applications of the method are to be investigated, and their suitability is to be analysed.

2 Scan-to-BIM

Currently, there are four different technical measurement methods used for building surveying.

- Electronic manual measurement, Tacheometry, Laser scanning and Photogrammetry.

The surveying methods can be further divided into point-based, which includes electronic manual measurement and tachometery, and area-based, which includes laser scanning and photogrammetry. In this paper, we consider the laser scanning method. 3D laser scanning is the process of capturing a real-world object or environment to gather information on its shape and appearance (e.g. colour). The collected data can then be used to create the as-built or as-is 3D model). A non-contact and non-destructive technology (Light Detection and Ranging (LIDAR) method) is used to create point cloud data. This point cloud data is used either for inspection or to make the 3D model [3]. With the augmentation of information to the created 3D model, a scan-to-BIM method is completed.

The scan-to-BIM workflow can be simplified into four steps.

1. Project preparation

Goal definition & Evaluation of the Existing Documents

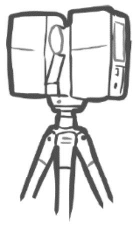
Required Level of Detail (LOD) & Level of Accuracy (LOA)

2. Scan data acquisition

Selecting the scanning device & Scan settings

Execution of the individual scans

Possible pre-registration



3. Registration

Registration into a cloud of measuring points

Clean-up of the data & Export to a suitable format

Documentation of the scan quality

4. Modelling

Import of point cloud data into the modelling software

Modelling of the components

Augmentation with information

Figure 1: Scan-to-BIM workflow

3 Market study and expert interviews

Software and hardware tools are an integral part of BIM implementation, and there is no digitisation without the software program. To adhere to the paper's aim involving laser scanning, a study on the available hardware for laser scanning is also necessary. Hence, this section aims to provide insight into the available hardware/software tools for 3D laser scanning. Table 1 provides the properties of the widely used 3D laser scanner.

To analyse the impact of Scan-to-BIM on building services more closely, seven expert interviews were conducted with employees of leading building services providers in the region of Aachen, Germany. The interviews covered the current workflows of construction progress control and the integration of laser scanning and digital twins. The experts are project managers and construction managers with comprehensive experience in their respective fields. To obtain a comparable result, all participants were asked the following seven questions in a 15-minutes interview:

- Do you work according to the BIM method in your company?
- Which software is used in your company for planning the building services?
- Do you use a software/ digital tool for construction progress control/ as-built recording?
- Do you have experience in laser scanning?
- How do you currently carry out the construction progress control?
- Where do you see the difficulties/ problems in the current workflow?
- What could improve the workflow, in your opinion?

The summary of the interviews is depicted in figure 2.

Table 1: Technical specifications - 3D laser scanner [9], [10]

	Focus S70	TX6	BLK360	RTC360
Manufacturer	Faro	Trimble	Leica	Leica
Type of scanner	Stationary	Stationary	Stationary	Stationary
Scan speed	1 million pts/sec	500,000 pts/sec	360,000 pts/sec	2 billion pts/sec
Scan rate	3 - 6 min per scan	3 - 6 min per scan	5 - 7 min per scan	2 min per scan
Communication	USB/Wi-Fi	USB/Wi-Fi	Wi-Fi	USB/Wi-Fi
Output format	.pts	.pts, .las	.pts	.pts
Additional device	Inbuilt OS	Trimble tablet or similar	iPad pro	iPad pro
Cost (approx.)	25,000 €	45,000 €	20,000 €	50,000 €

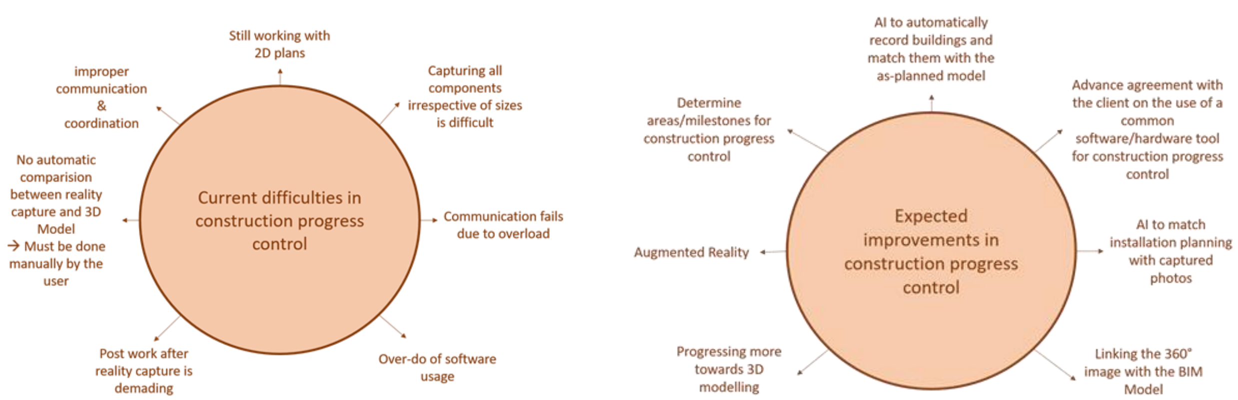
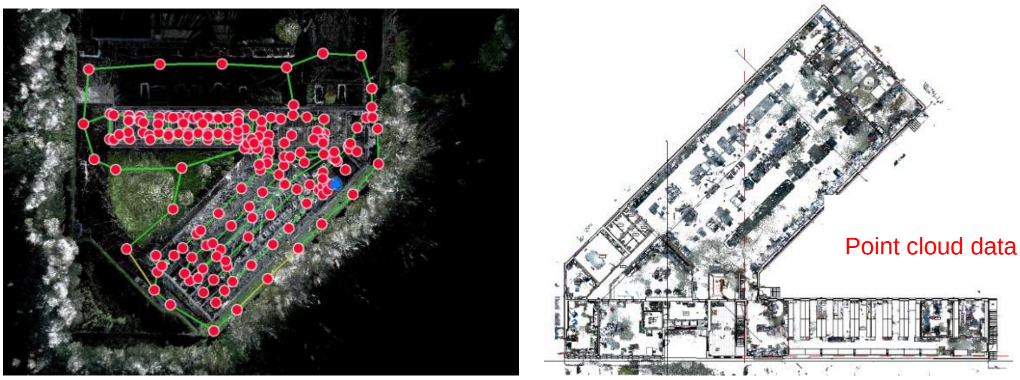


Figure 2: Overview of the results from expert interviews

4 Impact analysis of Scan-to-BIM method on design and construction of technical building services – Case studies

4.1 Scan-to-BIM method for energy analysis of existing buildings (Design phase)

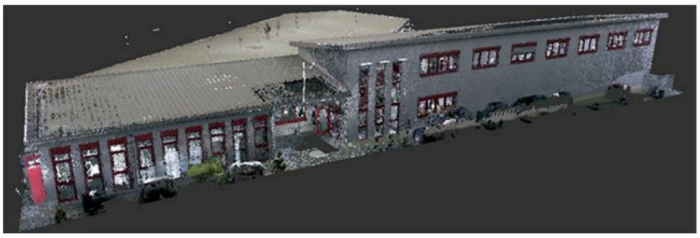
To analyse the suitability of the Scan-to-BIM method for energy analysis, an existing building was captured using the Leica BLK360 laser scanner and processed through the Leica Cyclone Register 360 software to create point cloud data. The point cloud data was then imported into the modelling software - Autodesk Revit and a 3D model was constructed (Figure 3a). Furthermore, the 3D model was augmented with heat transmission information attributes for walls, windows etc., thereby creating a BIM Model.



(a)

Heating Load Calculation Results

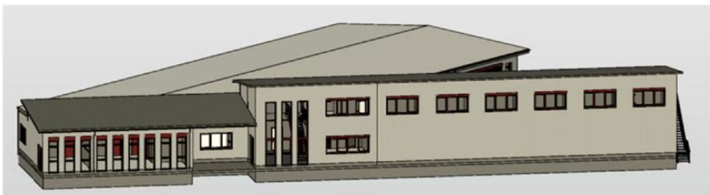
		liNear	ETU
Gebäudedaten			
Nettogrundfläche	A_{NGF}	1493 m²	1495 m²
Nettovolumen	V_{build}	8058 m³	5350 m³
Hüllfläche	A_{env}	2937 m²	2389 m²
Wärmeverluste			
Transmission	$\sum\Phi_T$	36654 W	40472 W
Lüftung	$\sum\Phi_V$	27631 W	24266 W
Heizlast			
Norm-Heizlast	Φ_{HL}	64285 W	64699 W
spezifisch (Fläche)	φ_{HL}	43 W/m²	43 W/m²



(b)

Energy balance – DIN V 18599

	Gesamt	Heizung	Kühlung	Lüftung	Beleuchtung
Nutzenergie	146026	112107	25367	0	8551
Endenergie	164088	135486	11596	2171	14835
Primärenergie	147006	95522	20873	3908	26703



(c)

Figure 3: (a) Point cloud registration from the Cyclone Register software; (b) Heating load calculation according to DIN EN 12831-1 (Left); Point cloud data of the building (Right); (c) Energy Balance calculation according to DIN V 18599 (Left); BIM Model from the Autodesk Revit software (Right)

The created BIM Model is then exported to the liNear software (through Revit Plug-in) and ETU Planer software (as an IFC file), and the heating load calculation according to DIN EN 12831-1 [4] was executed. Furthermore, according to DIN V 18599 [5], energy balance calculations were performed using the ETU Planer software [6], as currently, the liNear software [7] cannot carry out energy balance for non-residential buildings. The results are depicted in figure 3b and 3c.

4.1.1 Result analysis - Scan-to-BIM method for energy analysis of existing buildings

The investigation has shown that the geometrical and non-geometrical data correctness of the model depends on the data format in which the model is available and the software interfaces used by the calculation programs. Due to insufficiently stored information and errors during the geometry export, both software tools had problems with the calculations. The results show that energy calculations in the form of a heating load calculation according to DIN EN 12831 and an energy balance according to DIN V 18599 based on a Scan-to-BIM model are possible provided the model contains all the required information to perform the calculations. The quality of the model significantly influences the quality of the results.

4.2 Scan-to-BIM method for construction progress control and revision documentation (Construction phase)

To analyse the suitability of the Scan-to-BIM method for construction progress control and creation of revision documentation, various existing technical rooms were captured using the Leica BLK360 laser scanner and processed through the Leica Cyclone Register 360 software to create a point cloud data. For construction progress control, the resulted point cloud data was uploaded onto the Dalux field platform [8], and a comparison was made between as-planned and as-built.

The interface from the Dalux program is depicted in figure 4. With the Dalux field application, a field test was conducted at the construction site to investigate the usability for project progress control. The user was able to visualise the as-built and as-planned scenarios together on one screen, and the program provides the possibility to create tasks such as adjusting the model as per the as-build situation or demanding queries on unfinished tasks as tickets. The construction manager could assign these tickets directly to the responsible stakeholder, facilitating transparent communication among the project participants.

Furthermore, the obtained point cloud data was used to create a 3D BIM model (figure 5a). This drafted BIM Model can be handed over directly to facility management as revision documentation and can be developed further as a digital twin. The point cloud model can also be used as a reference for installation planning of new components (renovation purposes) without developing a 3D model, which results in considerable savings in terms of time and effort (figure 5b).

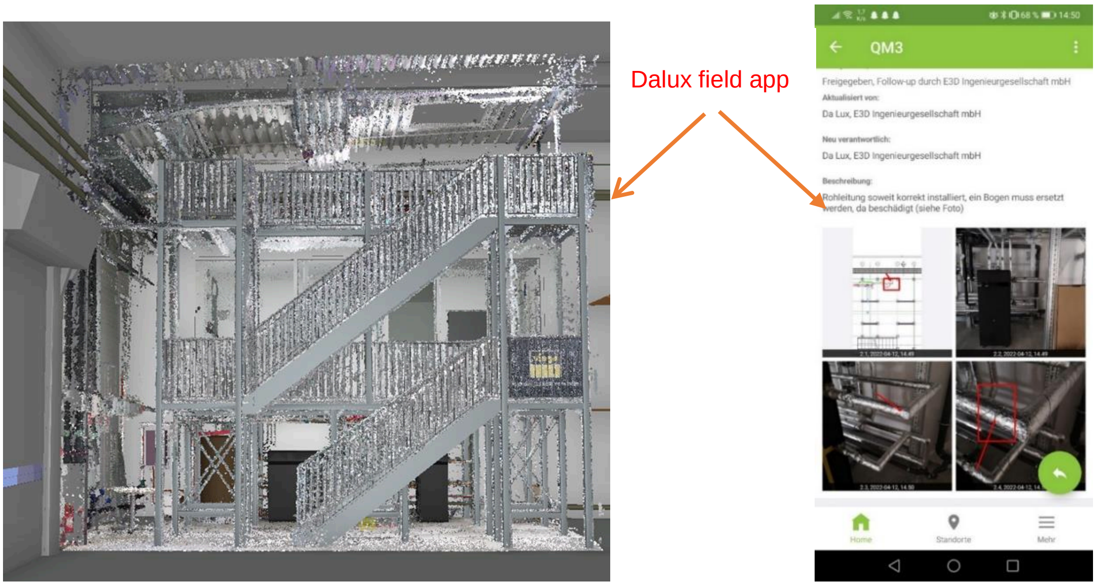
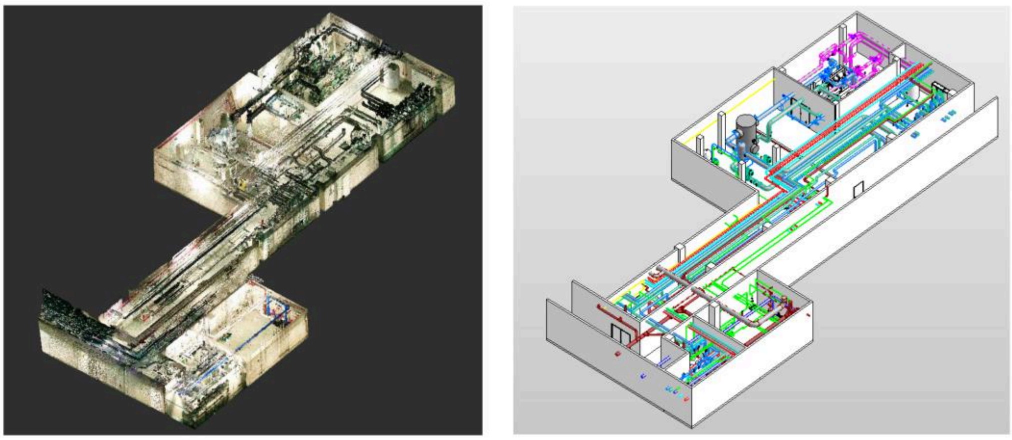
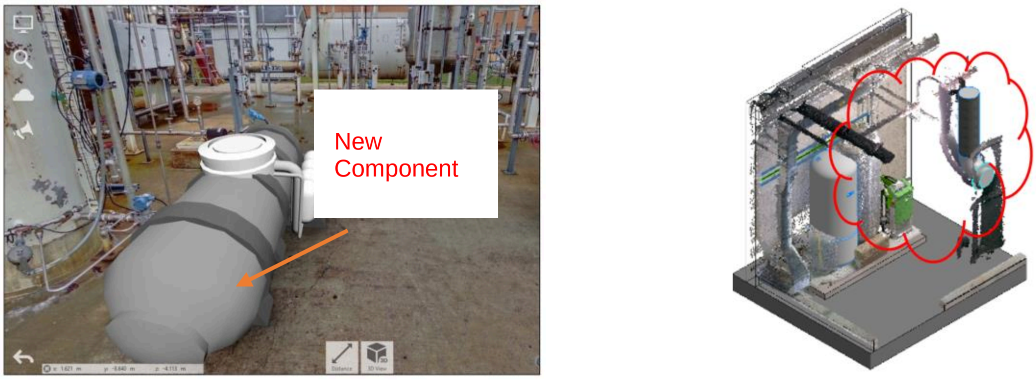


Figure 4: Screenshots from Dalux field applications showing the import of point cloud data



(a)



(b)

Figure 5: (a) Creation of 3D model from point cloud data; (b) Planning of new components with point cloud as reference (Left); Comparison of point cloud data with installation model (Right).

5 Conclusion

As with any building data model, the user must ensure the geometrical and non-geometrical quality of the scan-to-BIM models to achieve adequate results for the intended calculations mentioned in section 4.1.1. The scan-to-BIM method proves to be effective in achieving the required geometrical quality in the model, which forms the base for energy simulations. The responsibility for the quality of the non-geometrical attributes lies primarily with the model author. In the construction phase, the scan-to-BIM process proves to be effective in the case of the creation of BIM model / digital twins for facility management and comparison/ adaptation of as-planned models with respect to the as-built scenarios by reducing the time taken and increasing the quality of the output compared to the conventional way of recording. For construction progress control applications, due to the demanding post-processing works of the captured point cloud data, it is not economically efficient to have the construction site captured regularly. Instead, a reality capture with a 3D laser scanner on planned milestones in the construction progress to check for discrepancies would be reasonable. Based on the above case studies, the scan-to-BIM process is beneficial for the user but also has its limitations in terms of demanding post-processing works and costs associated with it. With the ongoing research in the combination of artificial intelligence with laser scanning for the automatic recognition of components, the scan-to-BIM process is set to have a significant positive impact in the field of technical building services.

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