Development of an Open-source Scan+BIM Platform

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Abstract -

In the last decade, a significant amount of research and development has been conducted at the intersection of Building Information Modelling (BIM) and reality capture data processing, mainly in the two areas often referred to as 'Scan-to-BIM' and 'Scan-vs-BIM'. Interestingly, it appears that all these advances have been made without the availability of any libre, cost-free and ideally open-source software platform that can handle both reality capture data (typically 3D point clouds and images) and Building Information Models. This paper investigates user demands and possible alternative options to develop such a *Scan+BIM* platform to further stimulate research in the field. A set of requirements for such a platform are first identified by means of a questionnaire sent to researchers and industry practitioners. Different software applications, identified from the literature and online, are then assessed against those requirements. A final ranking of these applications is conducted and one suitable solution is identified and suggested for development. The proposed solution combines the OpenInfra Platform, as a BIM and point cloud engine and viewer, and the xBIM Toolkit to provide complementary tools for the BIM engine. This new piece of software is currently under development and the authors intend to make it available to the Construction Informatics community soon.

Keywords -

Reality Capture; Point Clouds; Images; BIM; Engine; Platform; open-source

1 Introduction

The last decade has seen an explosion of research in Construction Informatics. Two fields that have received particular attention are reality capture data processing as well as Building Information Modelling (BIM), the latter being the development of structured data supporting collaborative processes for reliable management of construction projects over their lifecycle [1, 2, 3].

Reality capture technologies have rapidly evolved and are widely used for digital documentation. Digital cameras are now cheap and ubiquitous, and are commonly utilised for the creation of 3D models by means of Structure-from-Motion photogrammetry (PG). Besides, accurate terrestrial laser scanning (TLS) technology is increasingly affordable. Other imaging technologies, such as thermal cameras and ground-penetrating radars, have seen improvements in data quality. And finally, there is an exponential growth in Internet-of-Things (IoT) sensors that can capture various environmental and structural characteristics to be used in the generation of BIM models — and by extension Digital Twins (DTs) — of buildings [4].

These sensors on their own are resulting in a significant increase in data that needs to be curated and processed to extract meaningful information that can support effective design, construction, operation and maintenance of the built environment. The processing of that data along with its structured recording for analysis and efficient retrieval is increasingly considered within a BIM/DT digital framework. While the work conducted here could eventually be extended to a larger set of reality capture data, this paper focuses on 3D (and colour) data acquisition technology, i.e. principally TLS and PG.

Examples of the combined application of TLS/PG and BIM technologies can be found across the lifecycle of built environment assets and can be categorised into three groups [1, 3, 5], discussed in more detail in the following sub-sections: Scan-to-BIM (Section 1.1), Scan-vs-BIM (Section 1.2) and Others (Section 1.3).

1.1 Scan-to-BIM

Scan-to-BIM refers to the process of capturing data of existing built environment assets and producing BIM models representing the *as-is* state of those assets [1, 3, 6, 7, 8]. Although this process has various applications, it is primarily employed for the production of BIM models of existing assets that are then used as a starting point for design of renovation works or for supporting Facilities Management (FM). Scan-to-BIM is an extremely lively field, where academic and private research groups compete in the development of algorithms that automate this process as much as possible (e.g. [9]). While various of the technologies mentioned earlier can be employed in this process, it is notable that the majority of current solutions consider as input laser scanned point clouds [9, 10]. Photogrammetric point clouds and their underlying imagery are also increasingly considered as a valuable input to the scan-to-BIM process [11].

1.2 Scan-vs-BIM

Scan-vs-BIM refers to the process of capturing data of existing built environments and comparing that data against BIM models representing the prior recorded state of those assets [12]. This process has been shown to be of value to progress and quality control during the construction phase of projects, in which case the BIM models are *as-designed* BIM models produced during the design stage [2, 6, 13]. The Scan-vs-BIM process can also be employed to support asset operational monitoring, in which case BIM models are the latest recorded *as-is* BIM models of the assets.

1.3 Others

Other research works also employ reality capture and BIM data, but in different ways. For example, a significant amount of Health & Safety research has been conducted that processes reality capture data (TLS, PG, range cameras, etc.) to detect hazards. In these works, the BIM model of the environment where the sensors are located can be used to provide contextual knowledge to enhance data processing performance [14, 15].

In a different manner, Lovreglio et al. [16] use BIM models and pictures of buildings for the production of Virtual Reality applications to train building occupants in evacuation during earthquakes.

2 Review of Scan Engines, BIM Engines, and Scan+BIM Engines

2.1 Point Cloud Engines

TLS and PG are the two main technologies currently considered in the Architecture, Engineering and Construction (AEC) domain for the acquisition of 3D (i.e. geometric, visual) data of construction assets. For both technologies, the output consists in point clouds containing millions of unconnected 3D points usually enriched with additional data such as: colour, intensity of the received signal, and/or thermal response. Visualisation and navigation of those point clouds are needed for an appropriate understanding and further analysis of the data and processing results.

TLS manufacturers commonly provide users with their own software for data processing and visualisation (e.g. Faro Scene [17], Leica Cyclone [18]). However, these solutions are usually under proprietary (i.e. close-source and non-free) licenses and only allow limited data operations, such as point clouds registration and cleaning. The proliferation of TLS, and therefore the explosion of 3D data processing, have encouraged the development of powerful free and open solutions for 3D data processing and visualisation in the last decade, such as CloudCompare [19] or MeshLab [20].

In the case of photogrammetry, both proprietary software (e.g. RealityCapture [21] and Metashape [22]) and open-source (e.g. Meshroom [23]) are also available for the generation and visualisation of 3D point clouds.

These tools employ well-recognised libraries for handling point clouds, such as PCL [24].

In general, colour information delivered by PG models is more reliable than the colour obtained by TLS devices [25]. However, 3D geometry is less accurate and processes to obtain high resolution point cloud are slower with PG in comparison with TLS.

2.2 BIM Engines

BIM relates to both the creation and the management of structured information on construction projects across the lifecycle of buildings. In BIM processes, visualisation is fundamental for a correct understanding of the asset and its evolution. Therefore, 3D BIM models constitute an ideal visualisation and navigation reference, upon which additional information can be linked, visualise and processed.

A number of BIM engines and viewers have been developed to date, by both academic research teams and leading design software companies, with the purpose of generating, modifying and visualising BIM models. For example, IFC Viewer [26] and the commercialised IFC Engine [27] can load Industry Foundation Classes (IFC) files, visualise the 3D geometry and explore additional non-geometric information through a navigation tree. A more complete solution is delivered by Areddo [28], which is a free but proprietary BIM viewer that can handle IFC files as well as point clouds. Areddo includes additional basic operations like measuring distances and producing cross sections of models. However, this is not an authoring tool, i.e. information cannot be modified. Modification of BIM models, including those stored under the IFC standard, is possible in Autodesk Revit [29], currently the most used tool for the authoring of BIM models. Other related industry proprietary software packages include ArchiCAD [30], and MicroStation [31].

The above solutions, while presenting various levels of capability, are also restrictive because they are proprietary (although some are cost free). Aiming to produce open-source alternatives that could be used, maintained and improved by a community of researchers, alternative solutions for handling and visualising BIM models have been developed in the last decade. This is the case of the xBIM toolkit [32], which includes libraries for the authoring (xBIM Essentials and Geometry) and a Windows Presentation Foundation (xBIM Xplorer) for rendering and visualisation of BIM models based on the IFC open data schema. Another solution, principally focused on infrastructure, is the OpenInfra Platform [33], which is able to handle BIM models and Geographic Information Systems (GIS) -related data, as well as point clouds (as further discussed below).

A crucial step for the visualisation of the geometry (i.e. 3D models) 'codified' in IFC files is the interpretation of this data and the subsequent generation of renderable models to be shown in a viewer. A variety of libraries have been developed for this purpose in the last decades. Examples of this kind of tools are the open-source ifcOpenShell [34], which is used by the BIM storage and management tool BIMserver [35], or ifcPlusPlus [36] — as well as the xBIM library mentioned above.

2.3 Scan+BIM Engines

Importantly with regard to the focus of this paper, few of the above BIM or point cloud software solutions are able to handle both BIM and point cloud data; and those that do provide various levels of functionalities.

Point clouds can be loaded into Revit, ArchiCAD or Microstation, a feature principally employed to facilitate the production of BIM models of existing structures. In the case of Revit, point clouds need to first be opened with a different piece of software, Autodesk Recap, which exports the data into a unique format readable by Revit. However, the main drawback in all cases is software cost.

As previously mentioned, the cost-free viewer Areddo can be used for visualising both point clouds (in `.pts` format) and BIM models (in `.ifc` format). This tool additionally provides basic functionalities related to visualisation, such as variations in lighting, shadowing effects and navigation; and measuring distances. However, neither point clouds nor 3D models can be modified with Areddo.

Another solution able to deal with point clouds and BIM models is OpenInfra Platform. This modular software, which is still under development, can load BIM models (in `.ifc` format) as well as point clouds (`.e57`).

In summary, it can be observed that, despite the recent explosion in the use of reality capture technologies and BIM methodology for managing buildings over their lifecycle, only a few software packages, mainly proprietary, can handle both reality capture and BIM data, and with limited functionalities in terms of data manipulation (visualisation and authoring for both). Areddo is a visualisation tool that lacks BIM authoring functionalities, and is unable to open standardised formats for point clouds like `.e57`. Besides, like Revit, Areddo is not open-source, which limits the flexibility often required for research.

The research community would be best served by an open-source solution that could handle the two types of data, allowing visualisation and manipulation (i.e. editing/authoring) of both. OpenInfra could be that solution. Although the platform is still under development, it offers great potential since it is both cost-free and open-source and has been conceived as a cluster of interlinked solutions for infrastructure and construction projects, which can be extended with additional tools or features according to the users' needs.

3 User Requirements

The identification of the best way to develop an open-source solution that can effectively handle both types of data first requires that the needs and requirements of its potential final users — i.e. R&D professionals from both academia and construction industry — are brought to light. To this end, an online questionnaire (see Subsection 3.1) has been created and sent to professionals around the world. Results from the questionnaire have then been analysed and the identified requirements are reported in Section 3.2. In Section 4, the existing tools and their functionalities (reviewed earlier) are then juxtaposed to the user requirements to identify the most adequate open-source solution.

3.1 Questionnaire

An online questionnaire was prepared to investigate how R&D professionals, both in industry and academia, work with BIM models and reality capture data. The survey, which can be found in the Annex, enquired about the tools these professionals are currently using, and whether the needs they might have are covered by the software package of their preference.

The questions were divided in three main blocks:

General (Questions 2 - 7): Professional background; experience with reality capture and BIM; their awareness of existing Scan+BIM tools; and their needs and preferences.

BIM functionalities (Questions 8 - 10): Open BIM formats and standards that should be handled by the platform; open mesh geometry formats to be loaded and saved; and the main BIM authoring functionalities (e.g. editing geometric and non-geometric information, changing the topology of the models).

Reality capture functionalities (Questions 11 - 14): 3D and 2D data formats; images and calibration; and functionalities, such as point cloud processing.

A number of questions use a 5-point Likert scale to ask about the criticality of certain functionalities. The scale goes from 1 (not important) to 3 (would be nice) and 5 (critical). For each question the average score is calculated to help highlight the parameters and requirements which were more relevant to the participants.

The questionnaire was disseminated to academics and construction professionals through specialised mailing lists and social networks (LinkedIn groups and Twitter), reaching more than 35,000 potential users. A total of 31 professionals completed the online questionnaire; 28 of which (90.3%) were academics or researchers and 3 of them (9.7%) worked for construction companies (Question 2). Amongst them, 21 (67.7%) responded to commonly work simultaneously with reality capture data and BIM (Q3).

3.2 Scan+BIM Engine Requirements

3.2.1 General requirements

When asked about their awareness of any 'off-the-shelf' Scan+BIM software platform (Q4), 71% replied negatively. Professionals who gave an affirmative answer to this question (9 out of 31) mentioned Edgewise [37] and Revit [29]. However, only 6 of those 9 people had used those existing solutions.

With respect to their R&D needs (Q5), participants were asked about the size, completeness and format of the datasets handled by such Scan+BIM tool. Table 1 summarises their responses. Note that in this and the following tables, values in bold correspond to those scores higher than the average for the responses to all 7 Likert-type questions, which we refer to as the 'global average'.

As can be seen, participants agreed with the importance of handling open data formats as well as with the development of an open-source tool where other users can contribute. Also, supporting geo-referenced data is appealing to the respondents. However, the score for *handling data from large environments* is below the global average which is $\overline{s} = 3.92$.

Table 1. Question 5: Considering the needs of those responding the questionnaire, "the Scan+BIM software platform should . . . "

Requirement	average	std. dev.
support geo-referenced data	**4.09**	1.14
be able to handle data covering large environments	3.68	1.36
be focused on working with open data formats	**4.55**	0.94
be open-source	**4.14**	1.06

Regarding handling data of different nature (other that point clouds and BIM), 24 participants (>75%) considered that these two sources sufficed (Q6). However, 7 mentioned the advantages of supporting additional data, such as pictures and Geographic Information Systems data.

Finally, from a low level (i.e. software development) perspective, most participants (51%) agreed on the use of the C++ language for the development of the Scan+BIM tool, although some of them (4) mentioned Python as a "versatile and easy to use" alternative (Q7).

3.2.2 BIM functionalities

Regarding the ability of the Scan+BIM platform to handle BIM models, participants were asked about data formats and extra functionalities that they would find of interest for such a tool (Q8). First, when considering the formats and standards proposed in the OpenBIM framework (see Table 2), all respondents essentially agreed about the need to support the `.ifc` format. This is the only standard of the list whose score is higher than the global average $\overline{s} = 3.92$.

Table 2. Question 8: "Regarding the ability of the Scan+BIM platform to handle BIM models, it should support. . . "

Requirement	average	std. dev.
IFC	**4.73**	0.86
IFD	3.45	1.02
MVD	3.35	1.06
BCF	3.38	1.21

In some cases, loading or exporting 3D mesh models could be valuable. Amongst the file formats proposed in Q9, Table 3 shows that `.obj` is the favourite option for those who answered the question.

Table 3. Question 9: "With respect to the ability of handling 3D meshes, the Scan+BIM software platform should support. . . "

Requirement	average	std. dev.
OBJ	**4.24**	1.11
PLY	3.85	1.11
STL	3.75	1.34
VRML	3.5	1.12
COLLADA	3.45	1.36

Finally, the preferred BIM functionalities to be included in the Scan+BIM tool (Q10) are summarised in Table 4. Although most of the proposed features obtained scores above the average, professionals gave priority to the ability of editing the geometry and the topology of BIM objects.

3.2.3 Reality capture functionalities

Following a similar pattern of questions as for the BIM functionalities, the participants were first asked about their

Table 4. Question 10: "Regarding the modification of BIM models, the Scan+BIM software platform should support. . . "

Requirement	average	std. dev.
editing of the geometric information of individual BIM objects (e.g. shape and location)	**4.45**	0.89
editing of the non-geometric information of individual BIM objects	3.77	1.13
editing of the geometric relationships (topology) between BIM objects	**4.23**	1.04
editing of the non-geometric relationships between BIM objects	3.5	1.16
the creation of BIM objects	**3.95**	1.11
the various BIM classifications	**4.23**	1.04

preferred file format for point clouds and pictures (Q11). As illustrated in Table 5, amongst the proposed point cloud file formats, most participants highlighted XYZ, PTS, PTX and E57 as being most important, with values above the global average ($\overline{s}$ = 3.92). Regarding the proposed formats for pictures storage, these obtained lower scores than the alternatives for point clouds, which could reflect the prioritisation of 3D data. Note that pictures can also be stored in `.e57` files.

Table 5. Question 11: "Amongst the following file formats, the Scan+BIM software platform should support. . . "

Requirement	average	std. dev.
E57	**3.95**	0.99
XYZ	**4.38**	0.89
PTS	**4**	1.09
PTX	**4**	1.05
PLY	3.74	0.85
PNG	3.84	0.93
JPEG	3.9	0.89

With respect to point-cloud related functionalities, the participants were asked about the features enumerated in Table 6 (Q12). The preferred option was the ability *to perform some common processing of point clouds*, followed by *adding or editing per point information*.

The last question of those was about the functionalities of the platform for handling pictures and associated features (Q14). Amongst the proposed operations (see Table 7), the most supported functionality was the *support of calibrated images*, the only requirement of this batch with a score above the average.

Table 6. Question 12: "Regarding point-cloud functionalities, the Scan+BIM software platform should support. . . "

Requirement	average	std. dev.
some common processing of point clouds (e.g. cleaning/filtering, segmentation, other)	**4.57**	0.66
adding/editing per-point information (e.g. additional scalar fields)	**4.19**	0.79
the simulation of the acquisition of point clouds (laser scanning)	3.71	0.98

Table 7. Question 14: "With respect to handling pictures and related features, the Scan+BIM software platform should support. . . "

Requirement	average	std. dev.
(externally) calibrated images	**4**	1.04
editing calibration matrices	3.82	0.94
editing images	3.23	1.20
the simulation of the acquisition of images (with or without calibration matrices)	3.45	0.89

4 Comparison of Existing Data Engines and Proposal of a Scan+BIM Solution

After evaluating the results obtained from the proposed questionnaire, the availability of the required functionalities that scored over the global average was assessed amongst current (commercial or free; closed or open-source) software solutions. In the following subsections, the obtained results are discussed for reality capture engines, BIM engines, and Scan+BIM engines. Note that the software packages are compared as 'out-of-the-box' solutions. The use of libraries or application programming interfaces (APIs) to supplement software functionalities is discussed but not considered in the comparison, since those potential solutions have not been implemented yet and, therefore, are not available for the above-mentioned end users.

4.1 Reality Capture Data Engines

A comparison between a number of solutions was performed to analyse how existing reality capture data engines met the requirements highlighted in the survey result as per questions 11 (Table 5), 12 (Table 6) and 14 (Table 7). As can be seen in Table 8, CloudCompare, MeshLab, Metashape and ReCap meet most of the requirements. In contrast, Reality Capture and Meshroom do not, on their own, fulfil the needs expressed in the questionnaire. All the engines offer *some common point cloud processing* functionalities like cleaning/filtering or segmentation, which is one of the most desirable and basic requirements. However, another highly scored requirement, *adding/editing per-point information*, is only met by CloudCompare and MeshLab. The reality capture engines were also compared based on the general requirements as per question 5 (Table 1). All the engines can work with open data formats and all support geo-referenced data, except Meshroom. However, only CloudCompare, MeshLab and Meshroom are open-source.

In summary, CloudCompare and MeshLab are the solutions which meet most of the desired requirements; and additionally, these are open-source solutions, enabling further development, if needed.

4.2 BIM Engines

Amongst the software solutions presented in Section 2, conventional BIM engines are compared in Table 8, considering the most voted requirements in questions 8 (Table 2), 9 (Table 3) and 10 (Table 4). The evaluated tools handling uniquely BIM objects are the open-source solutions IFC Viewer, xBIM Xplorer and BIMserver. Although the IFC file format is supported by all, the most voted file format for the storage of meshes (i.e `.obj`) is only supported by BIMServer. Additionally, further editing or creation of BIM objects is not in the scope of any of these engines, that basically act as BIM objects viewers only. However, it is worth mentioning that xBIM Xplorer could take advantage of the xBIM toolkit to supplement its functionalities and provide the user with the ability of modifying BIM elements. With respect to the general requirements of question 5 (Table 1), all engines are open-source and allow working with open data format, supporting geo-referenced data.

Commercial solutions such as Revit, Microstation and ArchiCAD, which are provided by renowned international software corporations, all enable, amongst their numerous functionalities, the usage of point clouds. The tree tools are capable of creating and editing BIM object and conduct some basic processing of point clouds. Microstation and Revit can work with most open data formats, whereas ArchiCAD supports limited open data formats. All three solutions are primarily closed, proprietary BIM engines with the capability of loading and visualising point clouds.

Areddo is a freeware and can visualise point clouds and BIM files. However, the range of file formats that can be opened is limited and no operations can be performed on the objects, either point clouds or BIM models.

In contrast, the OpenInfra Platform can manipulate both point clouds and BIM models and is a free open-source solution, which facilitates the addition of new tools and functionalities to the platform. An important advantage of this solution in contrast to all previous ones is its ability to visualise and modify point clouds (as it uses the CloudCompare engine). But, a limitation of OpenInfra is that it offers no native functionality to create and edit BIM objects.

Overall, as shown in Table 8, Revit, Microstation and ArchiCAD meet most of the requirements pointed out in the questionnaire. Although the IFC file format is supported by all engines, the most voted file format for the storage of meshes (i.e. OBJ) is only supported by Microstation. And functionalities related to the creation and editing of BIM objects are only supported by Revit, ArchiCAD and Microstation. Regarding other general requirements, all engines allow working with open data format and support geo-referenced data.

As evident from the comparison above, solutions able to handle BIM models are clearly separable in two different groups: a first group including solutions that cover more requirements, but are closed, proprietary software (ArchiCAD, Microstation, Revit); and a second group with tools that provide comparatively fewer functionalities, but are these are free and open-source which makes them comparatively more flexible to the needs of researchers (IFC Viewer, xBIM Xplorer, BIMserver and OpenInfra). However, in most solutions enumerated in the first group, additional requirements cannot be implemented, since their source code is not available to the general public. In some cases (e.g. Revit), companies provide APIs that can be used for the implementation of supplementary functionalities, but these can be limited and/or complex. On the other hand, amongst the solutions listed in the second group, only OpenInfra can handle both point clouds and BIM objects, but it lacks object editing functionalities.

Therefore, one good solution identified and suggested for development combines OpenInfra, as a BIM and point cloud engine, and the xBIM toolkit that provides supplementary libraries for the BIM engine such as the (semi-)automatic generation of IFC files.

5 Conclusion

This paper presented the first steps on the development of an open-source Scan+BIM platform. First, the authors reviewed a number of existing alternatives that are able to handle point cloud and BIM data, analysing their advantages and disadvantages were highlighted. Considering the main functionalities provided by these solutions, a questionnaire was then sent to potential users of such platform

Table 8. Assessing existing Scan and BIM Engines against the key requirements identified from the questionnaire.

	Reality capture					BIM			Scan+BIM				
Requirement	CloudCompare	MeshLab	RealityCapture	Metashape	Meshroom	IFC Viewer	xBIM Xplorer	BIMServer	ArchiCAD	Microstation	Revit + Recap	Areddo	OpenInfra
IFC	-	-	-	-	-	✓	✓	✓	✓	✓	✓	✓	✓
OBJ	-	-	-	-	-	×	×	✓	×	✓	×	×	×
editing of the geometric information of individual BIM objects (e.g. shape and location)	-	-	-	-	-	×	×	×	✓	✓	✓	×	×
editing of the geometric relationships (topology) between BIM objects	-	-	-	-	-	×	×	×	✓	✓	✓	×	×
creation of BIM objects	-	-	-	-	-	×	×	×	✓	✓	✓	×	×
the various BIM classifications	-	-	-	-	-	×	×	×	✓	×	✓	×	×
e57	✓	×	✓	✓	×	-	-	-	✓	✓	✓	×	✓
XYZ	✓	✓	×	×	×	-	-	-	✓	✓	✓	×	✓
PTS	✓	✓	×	✓	×	-	-	-	×	✓	✓	✓	×
PTX	✓	✓	×	✓	×	-	-	-	×	✓	✓	×	×
some common processing of point clouds (e.g. cleaning/filtering, segmentation, other)	✓	✓	✓	✓	✓	-	-	-	✓	✓	✓	×	✓
adding/editing per-point information (e.g. additional scalar fields)	✓	✓	×	×	×	-	-	-	×	×	×	×	✓
(externally) calibrated images	×	✓	✓	✓	✓	-	-	-	×	×	✓	×	×
support geo-referenced data	✓	✓	✓	✓	×	✓	✓	✓	✓	✓	✓	×	✓
able to working with open data formats	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
be open-source	✓	✓	×	×	✓	✓	✓	✓	×	×	×	×	✓

(i.e. academics and construction professionals, principally researchers) to collect their needs and requirements for a Scan+BIM software platform. After analysing the data obtained from the questionnaire, the authors concluded that a combination of available open-source solutions, specifically OpenInfra Platform and xBIM toolkit, would be the starting point for the development of the proposed software platform. The authors are in the process of developing that solution and intend to make it available to the Construction Informatics community soon, for the benefit of the research community in particular.

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Annex: Scan+BIM Questionnaire

Question 1: I have read and agree the above information and its privacy policy and consent to the BIMERR Consortium using this information for research purposes.

Question 2: What is your professional profile?

Question 3: Does your research and development (R&D) activity require you to work simultaneously with reality capture data (point clouds and/or 2D pictures) and Building Information Models (i.e. semantically rich 3D models)?

Question 4: Are you aware of any 'off-the-shelf' (or at least easily accessible/implementable) Scan+BIM software platform?

Question 5: When thinking about your R&D needs, to which extent do you agree with the following statements about such a Scan+BIM software platform? [1 (disagree) to 3 (partially agree) to 5 (fully agree)]

- The Scan+BIM software platform should support geo-referenced data.
- The Scan+BIM software platform should be able to handle data covering large environments (e.g. urban and regional scale).
- The Scan+BIM software platform should be focused on working with open data formats.
- The Scan+BIM software platform should be open-source.

Question 6: Should the Scan+BIM software platform handle data of different nature (other than point clouds and BIM)?

Question 7: In which language should the Scan+BIM software platform be developed?

Question 8: To which level the following BIM open data formats should be supported by such a Scan+BIM software platform? [1 (not important) to 3 (would be nice) to 5 (critical)]

• IFC • IFD • MVD • BCF

Question 9: To which level the following other mesh geometry open data formats should be supported by such a Scan+BIM software platform? [1 (not important) to 3 (would be nice) to 5 (critical)]

• OBJ • PLY • STL • VRML • COLLADA

Question 10: To which extent do you agree with the following statements about BIM-related functionalities of such a Scan+BIM software platform? [1 (not important) to 3 (would be nice) to 5 (critical)]

- The Scan+BIM software platform supports editing of the geometric information of individual BIM objects (e.g. shape and location).
- The Scan+BIM software platform supports editing of the non-geometric information of individual BIM objects.
- The Scan+BIM software platform supports editing of the geometric relationships (topology) between BIM objects.
- The Scan+BIM software platform supports editing of the non-geometric relationships between BIM objects.
- The Scan+BIM software platform supports the creation of BIM objects.
- The Scan+BIM software platform supports the various BIM classifications.

Question 11: To which level the following Reality Capture open data formats should be supported by such a Scan+BIM software platform? [1 (not important) to 3 (would be nice) to 5 (critical)]

• E57 • XYZ • PTS • PTX • PLY • PNG • JPG

Question 12: To which extent do you agree with the following statements about point cloud-related functionalities of such a Scan+BIM software platform? [1 (not important) to 3 (would be nice) to 5 (critical)]

- The Scan+BIM software platform supports some common processing of point clouds (e.g. cleaning/filtering, segmentation, other).
- The Scan+BIM software platform supports adding/editing per-point information (e.g. additional scalar fields).
- The Scan+BIM software platform supports the simulation of the acquisition of point clouds (laser scanning).

Question 13: Are there other important, possibly critical point cloud-related functionalities that should be available in such a Scan+BIM software platform?

Question 14: To which extent do you agree with the following statements about 2D image-related functionalities of such a Scan+BIM software platform? [1 (not important) to 3 (would be nice) to 5 (critical)]

- The Scan+BIM software platform supports (externally) calibrated images.
- The Scan+BIM software platform supports editing calibration matrices.
- The Scan+BIM software platform supports editing images.
- The Scan+BIM software platform supports the simulation of the acquisition of images (with or without calibration matrices).