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Deconstruction project planning of existing buildings based on automated acquisition and reconstruction of building information

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ABSTRACT

During their lifecycles, buildings are changed and adapted to the requirements of generations of users, residents and proprietaries over several decades. At the end of their life time, buildings undergo either retrofit or deconstruction (and replacement) processes. And, modifications and deviations of the original building structure, equipment and fittings as well as the deterioration and contamination of buildings are often not well documented or only available in an outdated and unstructured way. Thus, in many existing buildings, incomplete, obsolete or fragmented building information is predominating and hampering retrofit and deconstruction project planning.

To plan change or deconstruction measures in existing buildings, buildings are audited manually or with stationary laser scans which requires great effort of skilled staff and expensive equipment. Furthermore, current building information models or deconstruction planning systems are often not able to deal with incomplete building information as it occurs in existing buildings.

We develop a combined system named *ResourceApp* of a hardware sensor with software modules for building information acquisition, 3D reconstruction, object detection, building inventory generation and optimized project planning. The mobile and wearable system enables planner, experts or decision makers to inspect a building and at the same time record, analyze, reconstruct and store the building digitally. For this purpose, a Kinect sensor acquires point clouds and developed algorithms analyze them in real-time to detect construction elements. From this information, a 3D building model and building inventory is automatically derived. Then, the generated building reconstruction information is used for optimized project planning with a solution algorithm of the multi-mode resource-constrained project scheduling problem (MRCPSP) at hand.

In contrast to existing approaches, the system allows mobile building recording during building walkthrough, real-time reconstruction and object detection. And, based on the automatically captured and processed building conditions by sensor data, the system performs an integrated project planning of the building deconstruction with available resources and the required decontamination and deconstruction activities. Furthermore, it optimizes time and cost considering secondary raw material recovery, usage of renewable resources, staff qualification, onsite logistics, material storage and recycling options.

Results from field tests on acquisition, reconstruction and deconstruction planning are presented and discussed in an extensive non-residential case study. The case study shows that the building inventory masses are quite well approximated and project planning works well based on the chosen methods. Nevertheless, future testing and parameter adjustment for the automated data processing is needed and will further improve the systems' quality, effectiveness and accuracy. Future research and application areas are seen in the quantification and analysis of the effects of missing data, the integration of material classification and sampling sensors into the system, the system connection to Building Information Modelling (BIM) software via a respective interface and the transfer and extension to retrofit project planning.

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1. Introduction and motivation[1]

In Germany, about 18.2 million residential buildings [76] and about 2.5 million non-residential buildings [17,21,33] account for the German building stock. Change and consolidation processes in buildings and infrastructures require comprehensive information to manage the reuse and recycling of the inherent materials in metropolitan areas of industrialized countries [34]. In their long lifecycles, user have changing requirements, and refurbish, retrofit, remediate or modernize buildings. And, changes often are not documented [63]. Thus, incomplete, obsolete or fragmented building information is predominating in many existing buildings, and result in partly unknown or uncertain building configurations [6,22]. Also, media discontinuities in the building documentation exist during a buildings' lifecycle and are prone to errors and regularly associated with loss of data [27].

To provide information for deconstruction[2] (and replacement) processes or change measures in existing buildings, buildings have to be audited previously. Building information of older, existing buildings is often saved in an unstructured way neither in Computer-Aided Design (CAD) nor in Building Information Modelling (BIM) format or not even digital. Thus, a direct processing of building information is often not possible or associated with a high modelling effort. In building deconstruction project planning practice, manual auditing is performed via manual measurements, examination of existing building documentation, (hard copy floor plans, views or vertical sections of the building or photographs), and checklists [35,36,47,50,66]. Today, deconstruction material masses are roughly calculated manually e.g. via percentage of gross volume [50].

In research and practice, there are some methods like manual measuring, image-based or range-based techniques to semi-automatically or automatically capture and process building information (e.g. [8,9,16,23,32,41,59,61,67,69]). Also, some commercial laser scanning applications of immobile total stations e.g. of LEICA are available.[3] The generated data is used for project controlling, progress tracking or product quality checking (Anagnostakis et al. [2], analysis of infrastructure (roads (Chen et al. [13]), bridges) or indoor navigation for robotic applications (e.g. [45]). The existing systems are costly and fragile [8,23,32] and have difficulties in scanning reflective, transparent and dark surfaces ([8,32]. Furthermore, great effort and skills are still necessary to process the data to a semantic building model [41,61,67,69].

A change towards mobility and affordability in the area of building reconstruction was achieved with the release of inexpensive, lightweight depth scanners like the Microsoft Kinect. In combination with high-performance graphics hardware, a lot of research was conducted in the field of registering and reconstruction of three-dimensional environments to increase the speed and level of detail of information capture and to reduce the ex post data processing. Based on their utilized feature primitives, the algorithms can be divided into different categories. The most prominent primitives are point features [14,19,25], plane features [44,60] and volumes [28,43,68]. These approaches already exhibit reliable reconstruction results. In addition, they offer an advantage for object detection over range-based only techniques, because RGB-D cameras, like the Microsoft Kinect, record images additionally to 3D geometry. While the object detection in recorded 3D geometry captured by range-based only techniques is computationally expensive, additional images provide the means to efficiently and automatically detect objects in the scene and relate them to the reconstruction result. Nevertheless, depth scanners are not yet utilized in industrial applications and have to be adapted and tested to do so and to benefit from their advantages. This is exemplary done in this work.

In practice of deconstruction building auditing, mainly manual measurement techniques are applied at site inspection. Often, also other building information such as existing building documentation or photographs is analyzed e.g. by checklists ([35,36,47,62,66,72]). In justified exemptions, material samples are tested for their environmental safety and material classification. But, current methods for existing buildings do not automatically compile a material inventory of the building yet e.g. for a buildings' material pass or for deconstruction and recycling reasons. Only approaches of that kind for new buildings based on BIM are known to the authors (e.g. [3,4,73]). An automated material inventory of an obsolete building would enable users to reduce manual effort in offer creation and risk assessment, as well as in waste documentation and management.

Recent trends show the shift of BIM usage in design processes to BIM usage in retrofitting and deconstruction projects [31,40]. Cheng and Ma [73] and Akbarnezhad et al. [3,4] use an existing BIM to quantify and roughly plan the scenario-based deconstruction of single buildings to calculate deconstruction and transportation costs, waste fraction amounts as well as energy and carbon embodiments. Project planning approaches based on sensor information in the construction and deconstruction of buildings and infrastructures are not known to the authors. Existing approaches are based on manual input only and focus on time or cost minimization (e.g. [51,52,57]), energy [56] or waste quantification and management (e.g. [3,4,37,73]), but are not linked with a sensor for automated building element recognition and information processing.

Fig. 1 shows the main project planning parameters in the field of deconstruction projects. The project planning itself has a certain scope and is based on the facility information, uncertainty, work or project activities and experience data. Table 1 shows the existing literature in the field, and its respective focus regarding the main project planning parameters. Also it shows the current gap in literature. The focus of this work is marked in grey both in Fig. 1 and Table 1.

Still, there is research needed when it comes to the usage of mobile (or wearable) sensors, their live-performance, their image resolution and the automated creation of a semantic building model (e.g. BIM). This would enable a faster building information capturing with no change of the existing walkthrough process during building auditing and a reduced ex post data manual processing. Additionally, incorporating cognitive vision algorithms allow for providing real-time feedback to the user during the scanning process and to guide him, e.g. to fill holes of the reconstructed model to avoid the need of subsequent recordings. Furthermore, the user is able to examine the digital model on-site for completeness and quality. This enables users to easily detected gaps in the model that might occur during sensing and reconstruction. Then, the user could immediately correct the recording in the areas which need a higher level of detail regarding the captured building elements.

Thus, a hardware and software system is developed that is able to acquire indoor building information via sensor and processes the information (see Section 2.1.1) into a building inventory (see Section 2.1.2) and a robust deconstruction project plan (see Section 2.1.3). The system was tested in a non-residential case study (an obsolete 5-story hospital) in Northern Germany (see Section 3).

2. System architecture and modules

In this section, the system architecture, the submodules and their interaction and data demand/exchange are shortly described and discussed. In the developed system, building information is generated in two ways: via sensor information and via user input.

The sensor information is captured by a Microsoft Kinect sensor - an affordable depth camera equipped with two cameras (RGB and infrared

[1] Parts of this contribution were already presented at SASBE conference 2015 in Pretoria (SA) in Volk et al. [63] and in Volk [65].

[2] This term is synonymously used with dismantling and describes the reverse construction process of buildings and facilities with a high degree of material separation and recycling.

[3] A review can also be found in ([62,63], Volk [65]).