Towards life cycle complete BIM

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Abstract –

The goal of Building Information Modelling (BIM) is the integral overarching digital modelling of all properties regarding a building as well as its construction. This is targeted through the integration and support of all involved experts. Due to the interdisciplinary nature of this task, the necessary data often only exists in a very fragmented and uncoordinated way throughout different departments. BIM tries to mediate between the different views of its users and allows for a coordinated accumulation of data, as well as synchronously keeping the planning status up to date. However, in most cases this available information is still not used throughout the complete lifecycle of the building. Clear gaps exist between the different phases of planning, construction as well as use and maintenance. Within this paper we aim to give an overview of possible BIM data, as well as its relevance for construction processes. This is especially considered from a process automation viewpoint, in order to identify the required interfaces as well as missing and irrelevant data for assembly processes within construction. Based on this a BIM informed design to production becomes possible. Primary goal is the development of strategies for the creation of BIM-aided planning processes that continue into actual fabrication and construction and are efficient in terms of time, energy and costs considering changing user demands and the resulting usage requirements. We address the lifecycle of a building using the concept of BIM. Therefore, we also consider the required information for future conversion and refurbishment of the building, in order to complete the lifecycle approach of BIM. Hence, we give a first brief overview of possible techniques for modelling pre-existing buildings within BIM, as well as the required level of detail (LoD). Looking closer at the LoD for different lifecycle phases.

Keywords –

BIM; automation; lifecycle; refurbishment; BIM to production

1 Introduction

The number of vacant buildings will grow due to structural changes while housing units are urgently needed [1]. To work against the housing shortage and to preserve the economic and ecological potential, existing buildings need to be efficiently checked and evaluated regarding their ability for conversion and refurbishment. If the estate is excluded for that purpose reuse and recycling need to be considered regarding their feasibility.

Currently Building Information Modelling (BIM) tries to streamline information flow within construction planning, while simultaneously allowing for a distributed workflow. The goal of BIM is the comprehensive digital modelling of all properties regarding a building. Apart from the constructive features this also implies the technical, functional and mercantile aspects. The basis for this integrated modelling approach are object-oriented and semantic-rich 3D building models. This opens up new opportunities within the highly interdisciplinary field of construction, because it improves the data exchange between all involved parties and leads furthermore to a distinct higher transparency for an optimized coordination. Discrepancies and errors can be revealed and corrected in the early planning phase, which is a crucial requirement for the safety that comes up with planning, firm and costs and also for the efficient building construction and exploitation.

However, this process requires additional effort, time and cost for the BIM planning, which can only be compensated if the construction process is streamlined through this method. BIM is currently often only used at the planning stages, while the actual assembly and construction still uses print outs of building plans.

Especially the area of construction and refurbishment, which are major parts of a building's lifecycle are still only loosely covered through BIM.

In order to move towards a more life cycle complete BIM we take a look at the current hurdles within the application of BIM as well as the difficulties and cost arising from Modelling existing buildings. We illustrate possible application scenarios as well as an outlook towards BIM informed process automation. In particular we focus on the digital reconstruction and refurbishment of existing buildings as well as first steps towards the planning of construction processes through BIM.

In the context of existing buildings new technologies, such as sensors and data programs, can provide complex information when only limited or no reliable documents about the building are accessible. This can be useful to base different planning decisions on. It is here considered to evaluate the conversion ability for future use scenarios basing on the building substance, its geometry and the material properties. For data collection the as-built detection in the architectural context was initially motivated by cultural heritage and preservation focusing on visual information. Non-visual information about the construction was needed when changes in the floor plan were made or in the case of refurbishment.

A 3D model including the information provided by sensor technology in combination with a matrix of interdependencies can provide a basis for decision in respect to the follow up function. This paper provides an overview of the methodology how to come from an existing building to the evaluation of the conversion ability for each scenario. It includes the phases of data generation, the role of a volumetric model including information (BIM), the criteria in the evaluation matrix which provides the results. A comprehensive state-of-the-art is introduced for each part. At the end the evaluation process is discussed outlining potential and research- as well as technological gaps.

The findings have been derived from literature review extending [2][3] and a limited part has been developed in small size tests. The methodology used to evaluate the ability (for reuse or recycling) has been developed in the research project RDFRS (Robotic Façade Disassembly and Refurbishment System) and has been further developed for educational purposes.

2 Data collection

The data needed to prepare the evaluation of a building can be grouped in geometric and material related information. Employing BIM additionally allows for the representation of metadata, like dimensions, functions, connections and part topology. Automating processes for this semantic association of parts is the research focus of Scan-to-Bim [3]. For each conversion scenario data from different groups are required. Excluding potential contamination is priority for all scenarios. Once via the geometric requirements are fulfilled, material testing is sensible. The acquisition of the building geometry delivers the bases to appoint later gathered material information in it.

Table 1 Assignment of conversion scenario and type of needed information.

Conversion scenario	Criteria to evaluate the suitability for each scenario	Geometry	Material
Refurbishment (building level)	Detecting contamination		X
	Structural safety	X	X
	Evacuation routes	X	
	Ability for conversion of floorplan	X	
Reuse (building component level)	Detecting contamination		X
	Modularization	X	X
	Economically sensible disassembly		X
	Structural integrity		X
Recycling (material level)	Detecting contamination		X
	Material purity		X
	Purity of fraction		X

2.1 Scan-to-BIM

For the geometry acquisition of buildings various surveying techniques can be used. The four basic common techniques are photogrammetry, terrestrial laser scanning (TLS), tachymetry and electronic devices for manual surveying. Data collection using 3D point clouds is the most common method for generating BIM compliant as-built models. The point clouds can be produced solely from imaging methods such as Structure from Motion (SfM) [4] or TLS [5]. TLS is the most common approach for point cloud generation with the purpose of as-built BIM documentation (Scan-to-BIM).

Although TLS delivers a dense 3D point cloud suitable for a detailed reconstruction of the building geometry, there are still a high number of manual steps necessary to utilize this data for more than visualization purposes. In order to be able to use this information in combination with BIM the data need to be matched to a set of building elements. Even though there are a number of concepts which try to determine building elements automatically from scan data, currently this is mainly a manual process. Additionally, there are only a few BIM systems capable of handling large point clouds as is necessary for a reconstruction of BIM from point cloud data. Point cloud data is often only used in the form of a planar projection onto two dimensional CAD drawing, which often results in a loss of information.

Even though the point cloud data itself is very high in quality, the modelling remains to a large extent a manual time consuming and cost intensive process. While this might be feasible for larger projects for the restoration of historically significant buildings, this is not a process applied comprehensively to the diverse field of restoration and refurbishment [2].

Even though a fully automated and flawless part recognition is envisioned and pursued, with the current state of the art this is still unrealistic [3]. The main problem that arise come from the conflict between a simplified and generalized BIM in contrast to a highly detailed representation of reality. Objects in real environments always have more characteristics and features than just those that are relevant or capable of being modelled. For instance a model building part might only require the parameters width, height and sill to floor height to be modelled. The 3D scan data however contains all geometric characteristics and details and needs to be able to determine, which information is or is not relevant. This requires an underlying model in order to associated and understand the context of the scan data.

Furthermore, point clouds typically do not fully describe geometries. Shadows in the field of view of the scanner create holes. Even though it might be possible to close some of these by matching multiple scans with different fields of view, there are many cases where a one hundred percent coverage is just not possible. For these holes in the point cloud a fully automated system must be able to fill in this missing knowledge. Manually we are able to do this due to spatial recognition and experience based reasoning.

2.2 Determining materials

Materials can be recognized by sensor technology due their reflectance to waves. The most common non-destructive testing (NDT) techniques are infra-red, ultra-sonic and imaging techniques as well as the less common in material determination radiography [6]. However in some cases these still require a preparation of the surface in order to reduce reflection due to irregularities. Simultaneously destructive testing methods can release previously sealed contaminants.

As these processes require a high number of manual tasks in addition to multiple visual on-site inspections, efforts have been made in the direction of automating aspects of non-destructive evaluation (NDE) [7].

However especially in historic buildings the challenges often are beyond identifying the material, but analyzing the origin and the transformation of the material over time. Due to environmental exposure, stress as well as possible repairs the structural properties of the material may have been transformed. However this information is specifically important for a structural analysis of the support structure and seldom analyzed to the extent of the required parts refurbishment.

Yet in order to better plan deconstruction processes of non-support bearing buildings parts at least a general knowledge of the material and thickness is required. Current building information models infrequently contain this information. Scan-to-BIM of existing buildings especially of historic buildings does currently not contain any construction documentation if not additionally modeled manually and costly [3][8].

This knowledge however is not only a requirement to plan deconstruction processes but also to determine if and how the refurbishment should take place. Potential contamination should be determined before a refurbishment scenario is considered. A common method to determine existing contamination within a building are air quality measurements as well as manual visual inspection of potential affected parts (e.g. HVAC systems for asbestos) combined with spectrographic material analysis for verification.

A 3D scan of the building site combined with camera imaging potentially allows to plan on-site inspection and necessary specimen sampling, beforehand. However even the aforementioned testing methods are able to miss concealed contaminants, which could potentially be uncovered during the refurbishment, most likely resulting in the end of the refurbishment project. Even in those cases a refurbishment could have been possible without disturbing the existing structure and therefore releasing the contaminant. This however would require a more cost efficient way to extensively determine hidden contaminants or at least indicators for further testing.

NDE procedures have the potential to do this, however these technologies often times require comparative results to measure them against and in most cases are not fully reliable. By combining a finite amount of building materials from BIM with 3D scan as well as NDE planning contamination testing can potentially be optimized for both towards efficiency and thoroughness.

3 Material as interface to building elements

Integrating a more accurate process of material information and potentially dimensioning of parts through Scan-to-BIM combined with NDE does not only allows for contamination testing. The resulting LoD can also be employed within construction process planning especially for potential automation scenarios. Currently contaminated construction site in most cases only allow for costly demolition and disposal of contaminated material. Automation of construction processes specifically through robotics has the potential to mediate the cost and reduce risk of injury. It is also possible to employ the created digital BIM directly for deconstruction and refurbishment planning. Within [9] we showed first concepts for employing digital parametric planning for assembly sequences execution with on-site adaptation.

A parametric robot control as provided by the KUKA|prc [10] allows for the individualized fabrication of parts through directly interconnecting CAD and robotic fabrication processes. These fabrication processes and the required machining tools are however highly dependent on the material of the fabrication part.
Planning robotics constructions is illustrated employing a layered model of building parts e.g. a wall structure as shown in Fig. 1 using the example of an Exterior insulation and finish system (EIFS).

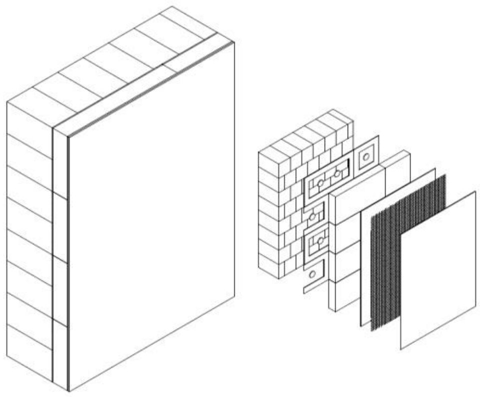

Figure 1. Layered model of an Exterior insulation and finish system (EIFS) consisting of: Walling, Bonding, Insulation, Reinforcement and plaster

Using a detailed knowledge of the layer structure allows for the planning of every subsequent deconstruction step for material extraction that allows for material separation, which is an important part of recycling.
However n difference to single part fabrication planning adaptation towards the modified environment has to be take into account for every layer. The complexity of assembly and disassembly is higher than pure material fabrication due to the interdependency of parts.
Using a layered approach a direct sequence can be planned for, however changes need to be captured by the system we recommend a sequential directly linked scan after every layer processing. Alternatively NDE data can be employed for a better approximation of each layer before deconstruction.

In addition to employing the layered model in order to inform a refurbishment process automated systems allow for a consistent feedback of all relevant construction data which extends the LoD of the model by adding details about positioning of parts as shown by Fig. 2, this in turn can be used for later refurbishment.

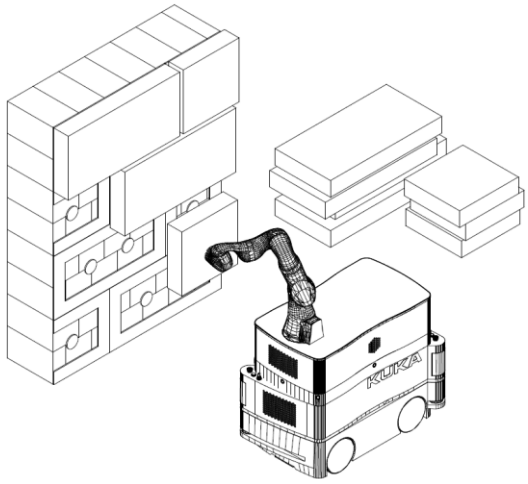

Figure 2. Robotics positioning of insulation plates with potential feedback of process data

4 Evaluation of the suitability for refurbishment, reuse or recycling

The motivation to keep as many estates as possible functioning (as named in the introduction) follows ecological motives to limit the impact on the environment while providing a long-lasting service. Whether a building qualifies for an additional use phase depends on complex factors which can be categorized in aspects regarding the site and the ones that result from the building physics. While the collection and processing of data on urban level is growing and with information providing tools like Geographic Information System, are already well established, in this context only the building physics is considered.

Fig. 3 shows the simplified hierarchy for scenario planning after a functional period ended. The sensor- and computer-aided processes basis upon on this and aims in providing relevant information in the appropriate planning phase.

For refurbishment, mostly geometric properties need to be investigated (see chapter 2). Lawful requirements, like the length and width of escape routes or the ceiling height are parameters which can be captured by sensor, measured and evaluated within the model. Additionally, individual requirements can be formulated and integrated within the comparison. The procedure works as a collision check, in which potential conflicts will be identified.

The suitability for reuse and recycling is impacted by the building capabilities, the resolvability from the construction context and the integrity of the element's functionality. For example, the building site should provide sitting area for heavy machinery and containers as well as the structure's and the adjacent building's cubature needs to allow the deconstruction [11]. The resolvability means providing material and components with an appropriate effort to disconnect a materials or components from one another. This includes resolvability between: component and component, material and component, material and material.

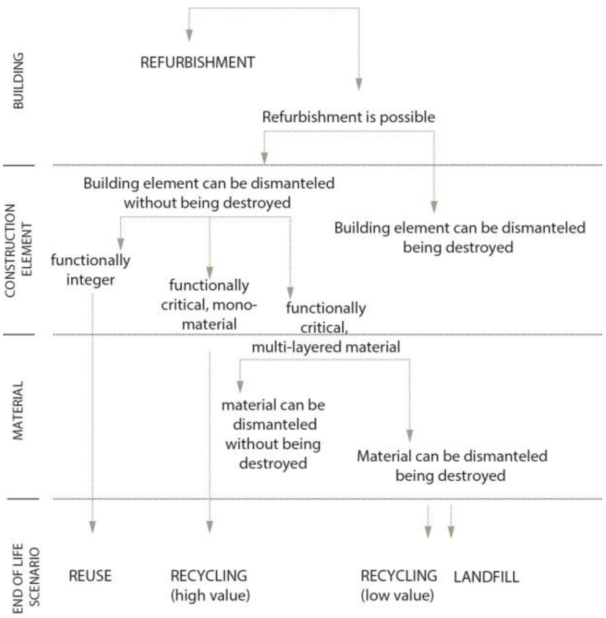

Figure 3. Simplified decision hierarchy for unused building substance scenarios

In order to indicate the level of resolvability the association of the material or products with the end of life scenario reuse or recycling (methodology developed by Durmisevic [12]; integration into BIM Markova [13]) can be found. Here a more detailed approach is used. The types of connection are differentiated regarding their level of connectivity which indicates their end of life potential. The following four categories are distinguished:

A) Non-destructively detachable
B) Destructively detachable (pure material)
C) Destructively detachable
   (mixed material same fraction)
D) Non-detachable

Reuse and recycling contribute to resource conservation and limit the emission production and should be applied if not the effort to disassemble is more intensive (resource and monetary). New material can be compared against the effort for the deconstruction. If the ecological impact/price of new product higher than the deconstruction and treatment, reuse and recycling is favorable.

The variation of environmental impact along building materials is reflected by an LCA based calculation. Materials can be investigated regarding their ecological footprint and the more relevant ones (high footprint) can be identified. The result is an integrated evaluation including the type of connection (based the four end of life scenarios) and the LCA calculation which can be used to argue for of suitable end of life scenario. These categories support both, the design decisions in the planning phase and evaluation for a conversion after the first usage phase.

5 Towards model informed construction process automation

The most promising approaches for as-built modelling of existing building with the required semantic model focus on matching scan data and an existing BIM. Accordingly the tested approach was therefore chosen for a preliminary examination. For construction process automation we focus on matching an existing as-planned model with the point cloud from laser scanning (Scan-vs-BIM). By using the knowledge about the deviations between the point cloud and the as-planned model we would like to move towards establishing a link between an abstract, generalized BIM and real world construction scenarios. While the use of BIM is still not as widespread as desired, it is gaining in popularity. However, the field of building assembly modelling is still theoretic only in most parts. Within section 3 we illustrated further how this link of sensor data with an underlying model can be used in order pursue construction process automation on site.

In order to enable renovation and refurbishment planning scenarios within BIM a very important aspect is the determination of used (also hidden) materials as well as possible scenarios of contamination. This is of significant importance especially for building materials that were commonly used during the construction of the building and are now considered harmful (e.g. asbestos, CFCs, Heavy Metal, PCB, etc.). Measurement methods by means of laser scanning, photogrammetry and especially radar, radiography etc. fundamentally seem to enable the collection of inventory data. Parameters like the reflectance or the scattering of the received measurement signal might give information also about material. In first tests we used a full-waveform laser scanner that allows analyzing the waveform of the reflected signal. Evaluating the echoes of the scan pulse (first pulse, last pulse) we could see variation in pulse width of TLS signals depending on the roughness of the material (Fig. 4). However, this field of research is partially at the outset. Distinct measurement methods are available. However, these methods need a structured, comprehensive and automated data collection. A calibration and validation of the derived knowledge from single applications in terms of a generalizability and transferability is necessary. As well as coupling and automatized processing of the just acquired data to the integration in BIM must be guaranteed.

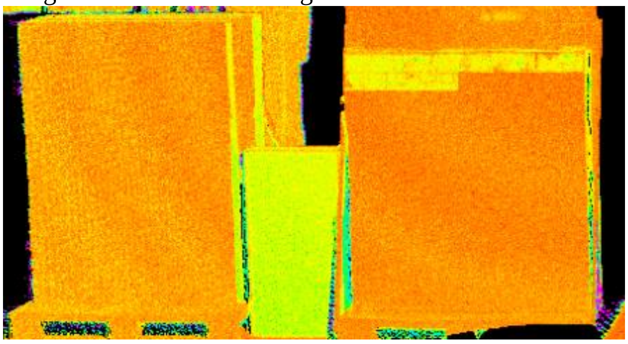

Figure 4: False color display of differences in deviation of the pulse shape of TLS signals

Within the current state of the art material determination is currently mostly still a manual process, especially for hidden materials, with exception to basic structural detection of studs and similar. Within support structures materials are often not only identified but a detailed measurement of material quality is executed (e.g. determining oxidation, carbonation etc.). Some works showed the potential of determining materials combining BIM as a reference database with NDE [3].
A layered material model as well as analysis of hidden parts can be employed as a basis for process planning. This would lead to a new view on BIM employing the used construction material as interface for each building element. Fig. 5 illustrates a first concept for this approach employing material classification for an informed refurbishment process planning.

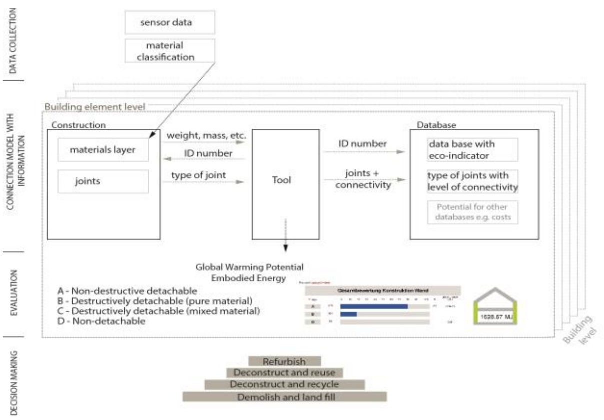

Figure 5. Next steps to integrate information on the building substance as planning parameter

6 Synopsis

Within this paper we took a further look at the current state of the art of using BIM for refurbishment and the relevance for construction process planning. Ilter and Ergen [2] showed that although both refurbishment and maintenance are an increasingly important research tropic current research tends to focus towards the topic of employing BIM for maintenance. We extended upon their identification of automation of post-processing 3D Laser scanning data for semantic association as a common goal within BIM research for refurbishment and maintenance. Additionally current challenges within the process chain from scanning to actual refurbishment were discussed.
While BIM allows for the modelling of all required information, as-built modelling is currently seldom at the necessary LoD required for actual process planning. In most cases a detailed modelling require a high number of manual steps which result in an even higher planning overhead than within design of a completely new building. Without further automation to some of these processes the cost for realization of refurbishment will stay too high for most projects.
However a number of potentials where identified for a better and comprehensive determination of construction materials. This would not only reduce contamination risk it also allows for a higher automation potential within construction processes.
Additionally a first draft for a material layer based planning of refurbishment processes was introduced. Within future work we will extend on this approach using matching existing BIM model with scan data for an on-site model for process execution.

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