IOP Conf. Series: Earth and Environmental Science **323** (2019) 012110 doi:10.1088/1755-1315/323/1/012110

# Information management throughout the life cycle of buildings – Basics and new approaches such as blockchain

**Ganter M[1,3], Lützkendorf T[2,3]**

[1]Student, Karlsruhe Institute of Technology, Karlsruhe, Germany
[2]Head of Chair, Chair for Sustainable Management of Housing and Real Estate, Karlsruhe Institute of Technology, Karlsruhe, Germany
[3]Centre for Real Estate, Kaiserstraße 12, 76131 Karlsruhe, Germany

manuel.ganter@student.kit.edu

**Abstract**. Ensuring sustainability for real estate is subject - among other aspects - to building related information. This information needs to be stored and updated continuously throughout the life cycle of a building. A delivery to buyers, tenants, consultants or other actors must be possible at any time. However, in most cases transactions cause significant loss of information while the issues associated with the "building passport" approach remains unsolved to date. Considering the long service life of buildings, various questions arise: (1) How to support data generation and storage within the life cycle and how to encourage actors to compete? (2) How to assure a high data quality and how to store it over a long period of time? (3) How to assure that all data users can track down the data owners at any point of time to manage compliance and legal issues? (4) Are there any new business models or new scopes for designers or other service providers? Information needs of actors along the life cycle are analysed and new information technologies (e.g. blockchain) are discussed. A relation to Building Information Modeling (BIM) is shown. Potentials of enhancing existing approaches regarding documentation retracing and accessibility of building and life cycle related information by using new technologies and IT are discussed; benefits of using a blockchain based system is pointed out by referring to existing pilot projects and first examples. Solution approaches for building passports are shown.

## 1. Introduction

The implementation of principles of sustainable development in design, construction, and use of buildings requires that the economic, environmental, and social impacts of each decision are taken into account. This demands a reliable and comprehensible basis for decision-making. The collection, processing, interpretation, transformation and communication of suitable information that supports decision-making thus becomes an essential prerequisite. In particular, the increasing adoption of life cycle analysis with its quantitative methods of life cycle assessment and life cycle costing, which is used to support design and investment decisions, requires a considerable amount of data. This also applies to the economic valuation, risk assessment and due diligence of buildings, which incorporate sustainability aspects to a greater extent than in the past. This requires the exchange of information between actors, the configuration of information flows along the value chains, appropriate information management and the application and further development of data processing systems. Indeed, information forms an essential basis for decision-making, but also legal and economic consequences are associated with it.

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd


www.manaraa.com

The "value" of information is growing, as is the risk of dealing with false or incomplete information. At the same time, it is a special feature of buildings that information must be stored over long periods of time and partly updated or supplemented. This raises a number of questions: (1) How to support data generation and storage within the life cycle and how to encourage actors to compete? (2) How to assure a high data quality over a long period of time? (3) How to assure that all data users can track down the data owners at any point of time to clarify on compliance and legal issues? (4) Are there any new business models or new scopes for designers or other service providers. These questions are explored in the present article.

## 2. Current trends in the demand for building-related data

At present, several developments can be identified that will lead to an increase in the demand for building and life cycle related data. These are among others:

- The introduction of level(s) [1]: The European Commission (EC) has developed the basis for a reporting instrument which serves to present and communicate sustainability-relevant features and characteristics of buildings. This is currently being tested. Among other things, the instrument deals with the effects of sustainability-relevant features and characteristics on the value of real estate and its development as well as the associated risks. For the first time, through the introduction of an indicator dealing with value creation and risk factors – namely indicator 6.2 – an attempt is made "to provide information on the reliability of the underlying data and calculation methods on which a reported performance is based."[1] This points to the need for a transfer of information from sustainability assessment to valuation and risk analysis with simultaneous quality control.

- The development of a taxonomy to record and evaluate the contribution of real estate projects to sustainable development [2]: The EC has launched an initiative on "Sustainable Finance." One sub-aspect is "green finance". The aim is to channel financial resources towards projects that contribute to sustainable development, particularly in the area of climate protection and resource conservation. This implies that in future banks will need reliable information on whether and to what extent a to-be-build or to-be-renovated real estate has an above-average environmental performance for project financing. This is to be achieved by means of a taxonomy that summarizes sustainability-relevant information in a form that can be interpreted by banks.

- New approaches for the development of lifecycle-accompanying object documentation in the form of building passports or building files [3]: In a current Global ABC initiative, an attempt is once again being made to agree on a format for the collection, administration and communication of building data that is required during the lifecycle by owners, administrators, experts or third parties. This is a continuation of efforts, in some cases lasting decades, to introduce building passports, which have not yet led to a result so far.

- The results of BAMB [4]: One of the main proposals resulted from a recent research project funded by the EU is the documentation of the material composition of buildings in the form of material passports. Further research projects go in a similar direction. There is a close connection with the goals of a circular economy.

- New guideline for waste audits before demolition and renovation works of buildings [5]: The guideline plans the compilation of information on the type and quantity of materials used in the building and on recycling possibilities in preparation for dismantling or conversion work. This can be facilitated by taking over information from the design phase of buildings.



www.manaraa.com

It becomes clear that the requirements for object data are currently growing, not only in terms of type and scope, but also in terms of quality, reliability and traceability. Thus, the following requirements for building- and life cycle-related data can be formulated. In particular, data should

a) meet the information needs of actors on selected occasions in the life cycle of buildings,
b) be extracted/processed to the extent possible from information already generated during design, construction and management processes in order to save time and money,
c) be permanently available - here in terms of lifecycle support -, including their history,
d) be updatable / overwritable and expandable, with the respective history,
e) be clearly assigned to a data source/author who vouches for the correctness of the information and assumes a corresponding liability,
f) be machine-readable / processable (e.g. BIM-compatible / BIM-able), and
g) be (globally) accessible when access conditions are met.

The listed requirements are important for different types of information. These are presented in Table 1 including a distinction between static and dynamically generated data.

**Table 1.** Selected types of information to manage in the life cycle of buildings (Lützkendorf)

| Type of information | static | dynamic |
|---|---|---|
| Information on location and land | X | (x) |
| Excerpt from the land register | X | (x) |
| Approval documents (e.g. building permit) | X | (x) |
| Planning documents incl. drawings - new building/updated (a) | X | (x) |
| Image documentation | | X |
| Expert reports (e.g. subsoil reports) | X | (x) |
| Participants in planning incl. contracts - New construction | X | |
| Participants in the execution incl. contracts - New construction | X | |
| Acceptance protocols and warranty periods - New construction | X | |
| Bill of materials – New construction/ updated | X | (x) |
| Cleaning, maintenance, repair instructions (e) – New construction/ updated | X | (x) |
| Energy performance certificate (always latest version) | X | (x) |
| Information on environmental and health compatibility (b) | X | (x) |
| Information on technical quality (c) | | |
| Other certificates (e.g. sustainability certificate) - New construction | X | |
| Insurance documents | | X |
| Usage data (Energy, Water) | | X |
| Usage costs | | X |
| Status of the maintenance reserve | | X |
| Documentation of maintenance activities | | X |
| Indications of possible pollutant inputs from use (d) | | X |
| Documents for reconstruction, (various, see new building) | | X |
| *If available, Leasing contracts (e.g. green lease)* | | *X* |

*(a) Incl. references to won competitions*
*(b) Incl. risks to local environment and health, with regards to the carbon footprint*
*(c) In particular with respect to stability, sound insulation & room acoustics, fire protection, moisture protection, thermal comfort in winter, thermal comfort in summer, visual comfort, accessibility, flexibility, rebuildability, deconstructability, recycling friendliness.*
*(d) e.g. for the use of buildings for chemical cleaning, industrial buildings, etc.*
(e) *Incl. indication of cycles*

From Table 1 it becomes clear that some documents created during the design phase must be updated and supplemented during the further use of the building. On selected occasions (e.g. lending, insurance,



www.manaraa.com

valuation, transactions), the information contained is passed on to third parties (e.g. valuers, insurance brokers, buyers) and used by them. Figure 1 shows examples of such information flows.

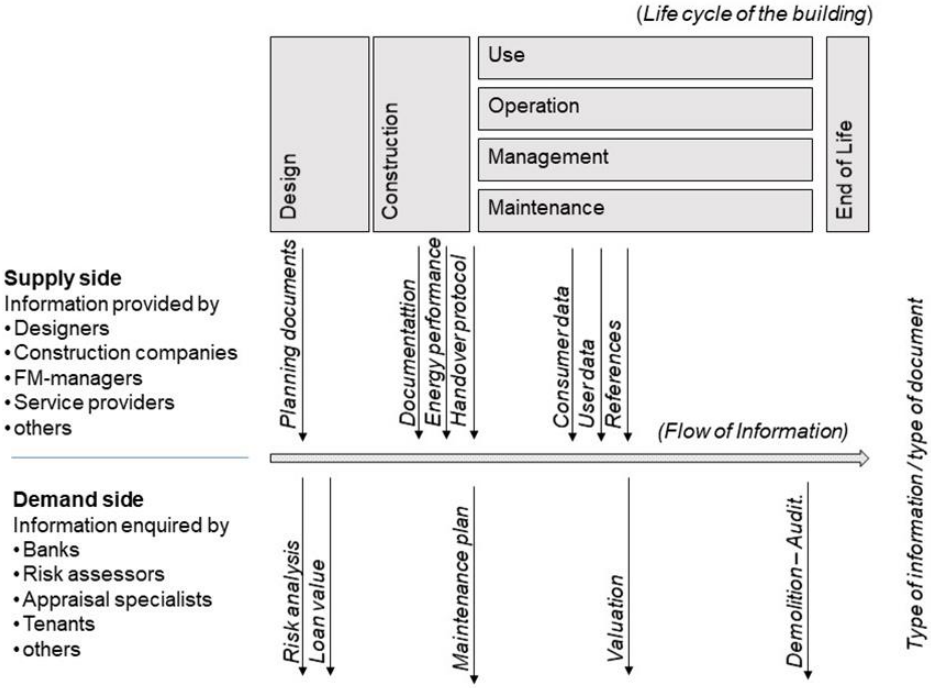


**Figure 1.** Selected types of information flows in the life cycle of buildings (Lützkendorf)

"*Globalization*" also leads to transactions in the real estate industry that are far away from traditionally known submarkets and thus to the need for reliable data on properties and market conditions at other locations. Ultimately, the trend towards "*Digitization*" offers solutions. To answer the above-stated questions, the possibilities offered by current IT solutions, such as BIM, databases/clouds and blockchains are discussed in the following.

## 3. Brief introduction of solutions

### *3.1. Building information modelling (BIM) and BIM Level*

BIM – a virtual model as the digital twin of a building – is an approach to support documentation and information flows during the entire real estate life cycle, from the early stage of conception through the more detailed design stages and the construction process (where it enables all parties to work on a shared model) and up to the operation and management of the complete building and its final deconstruction. The concept has been around for years; however, it had a major focus on the design and construction phases [6]. Since all building- and material-related information is stored in a central location from the start of the design phase, BIM shows great potential for embodied and whole life carbon calculations, especially in the early design stages [7]. To speed up and support the process of implementation during all phases of a real estate life cycle, the so-called BIM Levels were introduced to give an assessment of the current implementation status of a model (referred to as maturity of a model). While Level 0 indicates that there is no collaboration and most information exist in printed or electronic printed 2D drafting, Level 1 includes first 3D CAD concept work, CAD standards, and file sharing over a common file sharing system. Level 2 is the first system with advanced knowledge and information transfer with implemented workflows between serval parties. The final level, Level 3, which is not fully defined yet, is considered as being a fully digital knowledge and information transfer characterized by full transparency and based on a single model shared between all participants.



www.manaraa.com

In addition to the introduction of the above-mentioned BIM-Levels to describe the maturity of a model there are seven, so called "dimensions", which describe how the included data is linked with each other. While all dimensions up to dimension 4 relate to data about the construction object and the construction sequence (compare to "design" and "construction" in figure 1), dimension 5 to 7 add additional information (everything following the construction phase in figure 1). Particularly dimension 5, the cost analysis, and dimension 6, the sustainability evaluation, are relevant when it comes to taking BIM further than the construction phase towards lifetime documentation and facility management. Existing literature shows benefits of using BIM as a facility management tool [8] but they clearly indicate that there are some open issues, as stated in section 2 of this paper. A lot of data such as energy consumption, maintenance or leasing contracts is dynamically generated and must be therefore frequently updated during the life cycle. This requires clear roles and responsibilities among the different involved actors.

### *3.2. Clouds and databases*

The concept of a database is nothing new, however, new possibilities of storing information globally accessible in clouds, including change histories, made it an attractive solution to storing information over the entire life cycle. Cloud based offers for real estate documentation are already available, including features such as valuation, data transfers to other users and active real estate management. Cloud and database solutions are the most popular solutions these days. However, it is important to distinguish between the stored data types. Some use digital databases for storing electronic print documents which are not (or only partly) machine readable, while others use it to store data, which is fully machine readable and ready to be processed. The later solution is the more advanced and complex solution, as it enables data-driven analysis without any human interaction. In order to get to this point, it is a key success factor to reliably transfer print information such as paper scans into machine readable data. There are a few solutions in the market already, but they all include manual support and are not very reliable yet [9].

Since BIM models can also be managed on servers or in clouds, it is difficult to make a clear distinction between these two technologies.

### *3.3. Blockchain*

Thanks to the strong development of Bitcoin [10], there has been a lot of attention to the topic of blockchain. A blockchain can be understood as a decentralized database whose entries are immutable [11]. Blockchains can be categorised in two major categories: "*Public Blockchains*" where everyone can compete, validate, and look at all transactions, and "*Private Blockchains*" where an invitation is required to contribute to the network. During the past year a new category has been forming called "*Hybrid Blockchain*." Hybrid Blockchain consists of private ledgers which are all registered in a public blockchain. This joins the benefits of both, full transparency and immutability from public ledgers and data privacy from the private ledgers [12].

The major benefit of this technology is the possibility of performing transactions without any trusted parties or middle man. Object of a transactions can be anything from cryptocurrencies like Bitcoin to properties or simple data. Once a transaction is validated, it is consolidated with other transactions to build a new block. To ensure that manipulation in the blockchain is prevented, a process called "hashing" is used compressing the content of the block into a string of a set length. The major benefit of hashing is that the output of the algorithm changes entirely, if a single character of the input is changed. As the hash of every block also contains the hash of its predecessor, it is assured that, if a block is manipulated, the error will cascade down through all blocks which have been added after it, revealing the fraud. In order to manipulate a transaction, one would therefore have to manipulate every single copy of the ledger at the same time, which is impossible.



www.manaraa.com

To finally add the new block to the existing chain and distribute it across the network, a consensus protocol is used. There are different implementations such as the proof-of-work or the proof-of-stake, all having in common to achieve a consensus between all users across the network about what the truth is and whether a block can be added or not [13]. In the current market, there is only a limited offer of solutions based on blockchain. The current development is mainly driven by two types of companies, on one hand, big software enterprises and, on the other hand, small startups with a major focus on real estate.

## 4. Discussion

The discussion addresses the questions raised in the introduction. Among other things, it is discussed whether and to what extent job-sharing approaches between different IT solutions can be developed.

### *4.1. How to support data generation and storage within the life cycle of the building and how to encourage actors to compete? (1) Addressing data requirements a) and b) in section 2 of this paper.*

Data generation, as the start of the data life cycle, is one of the most crucial points of data management since this sets the base for all further activities, such as data interpretation and data transfer.

When it comes to the question of where and when to register a property in a blockchain or a cloud, a potential link to BIM can be seen. As BIM is currently mainly used during the design and construction phase – the start of every real estate life cycle – this could be a promising entering point. BIM up to Level 2 and dimension 4 covers all relevant information, such as plans, materials used and contractors involved in the construction process. Once the construction process is completed, the BIM Model could - from the point of view of the authors - be transferred into a Blockchain assuring that no information gets lost. At the same time, it builds a framework for future information flow (compare figure 1) within the remaining life cycle of the real estate. To ensure a smooth transition, industry standards like the IFC (Industry Foundation Classes) [14] are of great help. To assure the usage of a format like this, political support in the form of setting requirements for minimal information which must be provided when transferring an object would be of great use. A further potential tool to assure information content and format standards could be based on the building passports, a certificate which is used to describe all relevant properties of a real estate. To support that data security during the construction process, it is also possible to link the blockchain to a BIM model as a backbone. [15] shows an interesting approach where all new information of a model update is consolidated in a new block, which is then added to the blockchain. This would lead to two major benefits: 1) The transition process from BIM to blockchain will be easier and more efficient and 2) data security can also be assured during the construction phase of a real estate.

Once the information is stored in a blockchain, an open question is how to convince property owners and property users to compete on keeping and updating all relevant information in a blockchain. For both sides, the most important requirement will be an easy-to-use and intuitive interface to make it as simple as possible for all users to compete. This is a very crucial point as this will be the first hurdle to take for users. The second major requirement is the verification process. Standard concepts such as the proof-of-work or proof-of-stake are based on monetary incentives for the miners to validate the added information [16]. When applying this concept to real estate documentation, the question of who will be the actor paying out incentives arises. In an ideal case, which assumes that a buyer is willing to pay a premium for a property if the data is complete and of good quality, the property owner could have this interest to pay for up-to-date information. However, looking at the current market situation, there are a lot of unexperienced actors who are not aware of the importance of good documentation. A lot of transactions are based on incomplete information with further data loss. Hence, one must find another compelling way to convince owners to compete. Only if banks and insurance companies demand consistent data more than before and make conditions more dependent on it, as it is intended with the new approach of taxonomies, the "value" of information will become clear and the willingness to pay for good information will increase.



www.manaraa.com

For data transfer from BIM to a cloud the transition is a lot easier to realize as no incentives or validations are required. In some cases, the original BIM model is even created and stored in a cloud environment right from the start [17]. Depending on the database structure, the BIM model could be included as the main structure of the data set or as part of additional information.

*4.2. How to assure a high data quality over a long period of time? (2) Addressing data requirements c) and d) in section 2 of this paper*

Data quality is one of the most important requirements when it comes to storing information along the life cycle of properties. Blockchain and its characteristics mentioned in section 3.3. can be a key success factor to improve the data quality of real estate information. Once information is included into a block of a blockchain, it can neither be changed nor deleted or lost leading to assured data consistency and quality. As an actor, who requires information, it will therefore be possible to search the blockchain for the information he/she needs, knowing that there is no risk of losing any information which has been added.

Depending on how a database or cloud is used, it could also lead to high data quality under the precondition that a change history can be stored, showing when information has been changed and what the initial value was. The major problem is that in these systems there is always an administrator who has full access and change authority. Therefore, the scenario of an actor manipulating information, e.g. in order to achieve a higher selling price, is something to keep in mind. In other words, it is not impossible to change information or delete change logs. Nevertheless, if industry standards such as the building passport would set the minimum information requirements which have to be documented this technology provides a solid data quality. The data quality of BIM is strongly dependent on the different models and the implemented dimension. Since there are no industry standards or minimum requirements yet, the data quality can be different in every model. In existing literature such as [18] the authors propose an interesting data standard as a combination of GIS proven data quality standards and ISO/TS 8000-1:2011 with focus on data provenance. By focusing on data completeness, metric accuracy, thematic accuracy, temporal accuracy and logical consistency the stored data would meet the required data quality over a long period of time. However, this would need to be ensured on a technology level, allowing to add information only if all standards are fulfilled. As of today, the current systems still do not have such capabilities and bear the risk of manipulation through the system administrator.

*4.3. How to assure that all data users can track down the data owners at any point of time to clarify on compliance and legal issues? Addressing data requirements e) and f) in section 2 of this paper*

Another useful characteristic of the blockchain technology is that at every point in time information can be tracked down to its owner/adder. In terms of compliance issues, this is a significant benefit when it comes to storing real estate information. A common issue is that there is no clear ownership for existing information. This causes problems when it comes to wrong information or bad decisions based on wrong information. Using blockchain to store all information would overcome this issue, always allowing to reach out to the data owner to clarify in case of uncertainty [19].

In most of the current cloud solutions an owner tracking including a change history is possible. Usually the history is even part of the user interface ensuring great visibility of the data ownership.

According to the data standards for BIM proposed in 4.2., a data owner and change log tracking is also possible in BIM models, given that it is supported on the technology level.

In all three cases, an open question which would need further investigation and research is how to handle the data ownership during transactions. As of now it is not clear whether the data ownership and data responsibility will be transferred to the buyer or stick with the actor who added the information to the blockchain in the first place.

*4.4. Are there any new business models or scopes for designers or other service providers?*

Thanks to the immutability of blockchain, a potential use case for blockchain is the creation of a blockchain based land registry. Sweden has been running a successful trial since 2016 with the target to



www.manaraa.com

extend and fully cover all properties in Sweden [20]. Furthermore, blockchain enables the tokenisation of properties which opens the opportunity to invest in pieces of properties, making it more affordable for everyone and not only actors with major liquidity [21]. Together with smart contracts, blockchain can also be used to manage properties and automate processes like maintenance work, rental payments and even contract management [22]. For designers and architects, it will be increasingly important to adapt to the current technology standards and build up expertise with the new tools. Design models should be offered as integrated solutions in currently existing industry standards to remain competitive.

The answers to the questions raised show that the IT fundamentals are available for improving information management throughout the lifecycle. Furthermore, a division of labour between the use of BIM in the design phase and systems for managing data over the life cycle are emerging. In the competition between these systems, it remains to be seen if this division of labour will succeed or if individual IT approaches will develop into complete solutions for the generation and management of "life cycle data", a term which was characterized in the context of a major project [23].

## 5. Use case and recommendation for action

For providers – e.g. prefabricated house manufacturers, who already hand over a house file to their customers today – there is the possibility of a permanent administration and provision of information. Using solutions available on the market (e.g. see [24] or [25]), the information types shown in chapter 2 can be stored with clear structure in a blockchain. In this case, the blockchains primary function is a database, which is forgery-proof and loss-free. Data such as information on materials used or the exact position of cables and pipes, which are often lost, are thus reliably stored. If a building is sold at a later date the buyer can see which materials were used in the construction and where pipes or cables are located for possible reconstruction work. Furthermore, a documentation like this is the starting point for blockchain-based real estate transaction [26] where the asset works as a digital security unit (DAI) [27].

Section 2 of this paper showed that the demand for building-related life cycle data is currently growing. This applies not only to new players (e.g. banks) on the demand side and the growing urgency and relevance (effects on property value and financing), but also to new occasions (deconstruction planning) and additional topics (bill of materials, life cycle assessment). Sections 3 and 4 demonstrate that suitable IT solutions are available. So, what is currently holding back the progress? The extremely heterogeneous construction and real estate industry has so far failed to clearly articulate the data needs of relevant actors on selected occasions. This is not a technical problem but a problem of content. Only if the demand for information can be clearly described approaches such as building passports can be developed further in a sustainable way. Therefore, an industry standard for structuring the exchange of information on buildings between involved actors in the life cycle of buildings is proposed. Available literature, including preparatory work by one of the present authors, provides initial approaches in this respect [28 – 32].

## 6. Summary and Outlook

Emerging technologies like blockchain and BIM have a great potential to support information management during the life cycle of real estate. Blockchain has a major benefit on the data security, however, one needs to carefully consider in which cases an implementation of a blockchain is beneficial. Thanks to the current development of BIM and databases/cloud computing it is also possible to secure information with its history. If there is a way to control the system-administrators it is the easier solution as of today. Still, blockchain will be a technology to keep in mind during the upcoming years and actors should have plans ready to quickly adapt to the technology if it becomes a new standard. Further business models such as making a real estate "blockchain-ready" or evaluating existing properties on the blockchain based on the stored information could be very profitable for actors who are quick to adapt.



www.manaraa.com

**References**

[1] European Commission (2017): Level(s) – A common EU framework of core sustainability indicators for office and residential buildings, *JRC Technical Reports*
[2] European Commission (2018): Action plan – Financing sustainable growth, *COM/2018/097 final*
[3] Global Alliance for Buildings and Construction - ABC (2018*): Global Status Report*
[4] Buildings as Materials Banks – *BAMB (2017) Framework for Materials Passports*
[5] European Comission (2018): Guidelines for the waste audits before demolition and renovation works of buildings, *EU Construction and Demolition Waste Management*
[6] Estman C. et al.,(1974), An outline of the building description system, *Research Report*, **No. 50**
[7] Bantelli A and Stevenson V, (2017), Building information modelling (BIM) as an enabler for whole building embodied energy and carbon calculation in early stage building design, *WIT Transaction on The Build Environment*, **Vol. 169**, 89 - 100
[8] Yalcinkaya M and Singh V, (2014), Building information modeling (BIM) for facilities management – Literature review and future needs, *Product Lifecycle Management for a Global Market : 11th IFIPWG 5.1 Int. Conf.*
[9] Islam N, Islam Z and Noor N, (2016), A survey on optical character recognition system, *Journal of Information & Communication Technology-JICT*, **Vol. 10**, Issue 2
[10] Urquhart A, (2018) What causes the attention of bitcoin? *Economics letters*
[11] Peters G and Panayi E, (2015), Understanding modern banking ledgers through blockchain technology: Future of transaction processing and smart contracts on the internet of money*, SSRN Electronic Journal*
[12] Saxena M, Sanchez M and Knuszka R, (2016), Hybrid blockchain data architecture for use within a cognitive environment, *United States Patent US20180129955A1*
[13] Zheng Z,Dai H, Chen X and Wang H, (2017) An overview of blockchain technology: architecture, consensus and future trends, *2017 IEEE 6th Int. Congress on Big Data*
[14] May M, (2013). *CAFM-Handbuch. IT im Facility Management erfolgreich einsetzen*
[15] (3. Aufl.). Berlin: Springer Vieweg.
*[16]* Foroglou G and Tisilidou A, (2015), Further applications of the blockchain, *12th Student Conf. on Managerial Science and Technology*
[17] Wong J, Wang X, Li H, Chan G and Li H, (2014) A review of cloud-based BIM technology in the construction sector, *ITcon*, **Vol 19**, 281-291
[18] Ariza-López I, Ariza-López F, Reinoso-Gordo J, Gómez-Blanco A, Rodríguez-Moreno C and Léon-Robles C, (2015), Data quality elements for BIM applied to heritage monuments, *XIII Int. Forum, La Vie dei Mercanti*
[19] Ramachandran A and Kantarcioglu M, (2017), Using blockchain and smart contracts for secure data province management, *ArXiv 2017*
[20] Chavez-Dreyfuss G, (2016), Sweden tests blockchain for land registry, *Reuters*
[21] Nowinski W and Kozma M, (2017), How can blockchain technology disrupt the existing business models?, *Entrepreneurial Business and Economics Review – September 2017*
[22] Deloitte The Netherlands, (2017), Blockchain and real estate – mining unexplored terrain
[23] Netzwerk Lebenszyklusdaten, Karlsruhe
[24] SAP Leonardo, Applications and Services, Retrieved from https://www.sap.com/products/leonardo/blockchain.html
[25] Microsoft Azure, Azure Blockchain Workbench, Retrieved from https://azure.microsoft.com/en-us/features/blockchain-workbench/
[26] Jumpertz, N. (2018). Die Immobilie 4.0 ist Blockchain-optimiert, Haufe News – Innovation und Technologie
[27] MakerDAO, DAI StableCoin, Retrieved from https://makerdao.com/en/
[28] Lützkendorf, T., & Speer, T. M. (2005). Alleviating asymmetric information in property markets: building performance and product quality as signals for consumers. *Building Research & Information*, ***33*(2)**, 182-195.



www.manaraa.com

[29] Miller, W., & Lutzkendorf, T. (2016). Capturing sustainable housing characteristics through electronic building files: the Australian experience. In *Sustainable Built Environment Conf. 2016 in Hamburg: Strategies, Stakeholders, Success factors, 7th-11th March 2016; Conf. Proceedings* (pp. 190-199). Karlsruhe Institute of Technology

[30] Lützkendorf, T., & Lorenz, D. (2011). Capturing sustainability-related information for property valuation. *Building Research & Information*, *39*(3), 256-273.

[31] Sesana, M. M., & Salvalai, G. (2018). A review on Building Renovation Passport: Potentialities and barriers on current initiatives. *Energy and Buildings*.

[32] Lützkendorf, T., Speer, T., Szigeti, F., Davis, G., Le Roux, P., Kato, A., & Tsunekawa, K. (2005). A comparison of international classifications for performance requirements and building performance categories used in evaluation methods. *Performance based building*, 61-80.



www.manaraa.com

Reproduced with permission of copyright owner. Further reproduction prohibited without permission.

www.manaraa.com