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Article

Digital Transformation Framework for Facility Management based on Building Information Modelling

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Abstract: The paper is based on the scientific outcome of a PhD Thesis. It introduces the generic, model-based, reusable, and extensible conceptual framework to incorporate Facility Management data based within the three-dimensional model-based design and construction of an asset to enable smart applications, which are introduced. The conceptual framework is composed of empirical data from expert interviews, questionnaires, and factual analysis from 13 projects of varied sizes of public and private clients. It shows which phases need which data, who needs them, and which added value can be generated if intelligent data structuring is used at the beginning of the construction project and bridges the gap between requirement and practice. The term "smart application" is introduced.

Keywords: conceptual framework; Information Modelling; Building Information Modelling (BIM); Facility Management; Smart Buildings; Smart Applications

1. Introduction

Building owners are dependent on accurate data for the FM. Yet the data currently available due to digital methods are mostly not structured or do not focus on the FM but on the shorter construction phase. The research gap consists of unspecified data and requirements at the beginning of a construction project that a client has for the facility management (FM) phase of an asset to operate it efficiently and effectively. Adding to this, it is not known how this data, if provided, can be used for the further development of services, such as smart applications. In an office building, these smart applications could be the development of an online tool based on Building Information Modelling (BIM) data that shows a user in the building which meeting rooms are currently available, instructions on accessing them, if and when they have been recently sanitized or if there are any restrictions in their use (faulty equipment, safety distances, etc.). These smart applications are based on the intelligent data structuring with BIM. It is therefore only possible to provide additional services and applications to the user, FM, and the public with an increased expenditure of resources.

Furthermore, there is no consistency of data from the initial project idea to planning, realization and operation. Data models are available that can only be implemented for comprehensive uses to a limited extent, as they are mostly evolved systems. So far, there are neither harmonized standards nor generally applicable rules for the life cycle-based information management of buildings, but only practice recommendations from bottom-up approach-driven industry associations, which do not focus on the building owner and client and their operational phase.

Following this research gap, it is necessary to investigate and derivate a conceptual framework for further analysis of the use of construction data for the operational phase. As an asset of public clients are investigated, this must be based on open and non-discriminatory data standards, which considers the distinctive features of the economic asset real

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estate, especially its long service life. Moreover, the need of customers and the particularities of the change from a previously process-driven to an information-driven construction industry, comparable with the Industry 4.0 approach.

It is proposed to suggest a life cycle based conceptual framework with the use of BIM generated data. This with the aim to use the data generated in planning and realization in the FM phase to foster innovation and to enable the owner of an asset to promote the further use of ordered and modelled data for smart applications by using the Design Science Research (DSR) approach. The proposed model of data structuring will be evaluated and validated in one or more projects. The work is based on open source and therefore discrimination free standards such as public standard Industry Foundation Classes (IFC) [1]. When reference is made to ISO standards, this refers to the main parts of the respective country-specific standards and not to national supplements, guidance, or tools. The ordering documents for these models were based on the so-called Project Information Requirements (PIR) and the Asset Information Requirements (AIR) based on the series of ISO 19650-1 and following numbers [2]. However, if the order documents did not comply with these PIR and AIR, the ordered data requirements were taken from the documents provided and adjusted in all conscience. The overarching Organizational Information Requirements (OIR), which contain the strategic objectives of the respective appointing parties, were not part of the survey as well as the Regulatory Information Requirements (RIR), which are not standardized yet and will not be in the medium term.

2. Existing knowledge

Although contributing to average 5 to 15 % to the countries national GDP [3,4], the construction industry (including real estate, infrastructure, and industrial structures) is one of the most indolent sectors in terms of digital transformation (cf. the extensive research of 5,6). Products manufactured by the construction industry are characterized by five principles: immobility, complexity, durability, costliness, and a high degree of social responsibility [7–9] and are commonly referred to as construction projects. Construction is defined as *"everything that is constructed or results from construction operations* [and] *refers to both buildings and civil engineering works."* [10] (p 8) *"It includes new work, repair, additions and alterations, the erection of prefabricated buildings or structures on the site and also construction of a temporary nature* […] *and can be carried out on own account or on a fee or contract basis"* [11]. The sector is associated with negative public relations regarding delays, budget overruns and low planning and execution quality, which has sufficiently been discussed by a plethora of authors (cf. the reports and studies of 12–15). Synoptically, construction projects are manufactured as unique, highly individual, handcrafted items on site at the customer's premises. This inevitably causes a chain reaction [16] leading to low margins, high risks, low customer satisfaction, time delays, budget overruns, significant numbers of defects [17] resulting in a negative image and a reputation for digital ignorance [18]. Knowledge on the construction site requires a high degree of empirical experience and can only be made interchangeable to a limited extent [19].

The dependable, automatic, and correct data transfer of asset data needed for the maintenance of a building from a finished construction project to an asset management data base of an owner using information management based on BIM is an unsolved problem [20–22]. It is not a lack of missing, insufficient, or faulty information and communication systems, the necessary technology has existed for years or decades [23–25]. Research mainly shows the lack of consistent and proven data structuring as opposed to availability, application, and deployment of proven IT-based tools [26–28], as already proven by other industries (cf. 29,30).

The compulsory consistent and sustainable use of this data for enabling added data-based services in the operational phase of an asset is insufficiently solved [31,32]. This information loss and incorrect transmission or insufficient interpretation of ambiguous data during the transition from the design and construction phase to the operational phase of built assets is leading to individual specifications and contractual agreements of clients

[33,34] and therefore a low spread of digital methods [35]. This discrepancy of non-existent and non-continuous data structuring can only be partially filled [36,37]. With current approaches and corresponding data models, requirements can only be implemented to a limited extent. [38,39].

Numerous industry surveys point out the significant importance of BIM but the low spread of information management in the industry [21,40,41]. In this context, information management can be defined as *"tasks of project management, which include the acquisition (design, retrieval, collection, selection), forwarding, handling, processing, evaluation and storage of project information (in formatted, unformatted, graphic, electronic or paper form)"* [42] (p 112). Integrated application of information management for FM is considered a new topic with the result that missing standardized data frameworks with the industry not capable to develop a necessary framework on their own [34,43], This leads to resilience to other successfully implemented transformations, such as those in the manufacturing industry. Consequently, for the successful acceptance of the built object, it is merely possible for the client to manually transfer data from the physical object for further use in other digital applications or digitally imaged building models [44–46]. Initial attempts are starting at the academic level to develop a framework [47–50]. It is important to recall that information, unlike tangible assets such as buildings, differs, inter alia, in the different degrees of reusability, reproduction costs, dissemination, costs of creation and use, and ownership [51] (p 2).

The interdependencies between a deficiency in data governance (DG) and the concomitant inadequacy of the use of data in the construction industry has already been discussed by 52–54 pointing to the necessity of a holistic, not temporary project-based approach. DG as a prerequisite for information management can hereby be defined as *"the formal execution and enforcement of authority over the management and focusses on authority and accountability for the management of data as a valued organizational asset. It refers to the allocation of decision-making rights and responsibility regarding the use of data and aims at maximizing the value of data assets in enterprises. This combines the clarification of decision levels, roles and responsibilities and needs to set up in a framework*" [55] (p 4),[56] (pp 241–243),[57] (pp 1–3),[58] (pp 229–232).

The principles of DG provide stakeholder value with a holistic and tailored approach covering an enterprise end-to-end by providing a dynamic framework which distinct from the quotidian management [59]. However, the information management based on digital planning and realization processes using BIM must be aligned with the business needs to be successful and create added value [60]. [61] affirms that value creation needs to realize benefits at an optimal resource cost while optimizing the associated risks (cf. the case study of [62]). Precisely the identical requirements were imposed by [63] (p 1036) generating added value for building owners *"to support the core business of the enterprise"*. One of the biggest issues, however, is to collect and process only the data necessary for the respective operation and its maintenance, a task called "*Data Minimization*" [64]. The objective of the consequently developed COBIT (Control Objectives for Information and Related Technologies) Framework [65] is to ensure a balance between value creation and the optimization of risks and resources related to the application of Information and Technology. It also defines the information cycle from the alignment between business and IT processes that generate and process data. These data transforms into information, which in turn becomes knowledge [66] (p 6). Value can be generated from this knowledge, from which business and IT are driven in a continuous improvement process [67]. Figure 1 shows the structure and dependencies of the information life cycle according to COBIT.

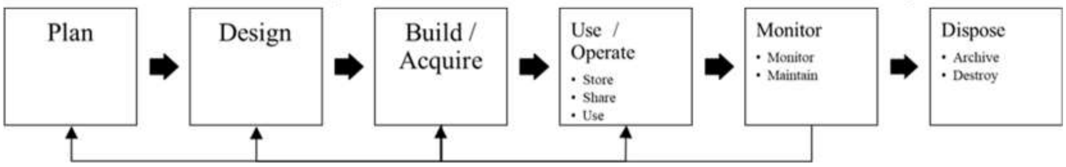

Figure 1. COBIT Information life cycle (own illustration)

This process scheme is comparable to the information accumulation and procedure in projects in the construction industry [53,68] with its tremendous need for data [69] to cover all necessary data to plan and construct all temporary intermediate conditions and final commissioning of assets of the built environment [70]. [71] (p 106) describes the situation as follows: „*a construction engineer [...] do not see themselves as data content manager. Yet, almost everyone is a data manager working with data content* ". This idiosyncratic understanding of the separation between information/data and delivered product (e.g., the constructed asset) in the construction industry is confirmed by [72]. Nevertheless, DG principles are common in other industries and have existed for decades [73,74], but are almost unknown in the construction industry [75], leading to a "*lack of accountability and responsibility for data related issues*" [76] (p 2).

Several authors advocate that it is because data is not valued or seen as an asset. [77–79]. DG is only partially existing in construction (compare the surveys of 75,80). In the event of an economic crisis, it is reinvented or developed, depending on the severeness of the crisis [81]. This behavior is evident even though DG is seen as a critical success factor for data science in asset management [82] (pp 431–432). More, research about DG for interorganizational settings is still in its infancy [83]. These interorganizational settings include networks, ecosystems of firms and platforms, with the settings of these are shaped by customers, vendors, collaborators, and other business partners [76,84]. [78] (p 6067) highlights that "*over time, these relations have evolved from dyadic relationships to the emergence of complex ecosystems*". This also applies to a significant extent to the construction industry, which, like a data ecosystem, is characterized by the presence of a "*socio-technical complex networks in which actors interact and collaborate with each other to find, archive, publish, consume, or reuse data as well as to foster innovation, create value, and support new businesses*", as stated by [85] (p 589).The consistent applicability of DG in the construction industry is another essential step to allow further growth in terms of digital issues, as already proposed by [70]. The ISO 19650 series of standards enables and supports this through the introduction of constraints for information management on enterprise and project level [86].

The challenges and problems outlined earlier are occurring in an industry that has not had to solve these or similar problems for decades - profit margins have been low but stable, and methods have not changed for centuries. [87]. A decade ago, this change took place in an equally large industry - the German manufacturing industry was faced with increasing repressive competition within Europe and abroad. The term Industry 4.0 was "created" due to the economic recession [88], combined with a fundamental data-based strategy to secure the future of the German manufacturing industry [89]. A co-benefit should be an additional competitive advantage over other competitors due to networked cyber-physical systems, smart tools, and smart data. It should prepare industry participants to use data-related methods, interconnect production devices and enable "smart solutions" (cf. [30]), i.e., the "informatization" of traditional industries [90]. Industry 4.0 has had a major impact on the manufacturing industries and is seen as a business transformation supported by technology rather than the opposite [91]. It is considered as one of the key factors of the implementation of Industry 4.0: The focus on permanent access to necessary information and its consequent use. This requires the networking of as many company processes as possible and the permanent access to all necessary information for automation of processes in a company and cross-company [92].

3. Results – framework

To be able to ensure the best possible research and development quality, the method of Design Science Research (DSR) is used for the specific question based on the specified delimitations [93].

3.1. Procedure in establishing the framework

According to [94] (p 1) the intention of DSR is to "generate knowledge about innovative solutions to real-world problems […] especially useful in researching the networked economy". [95] suggest an implementation in interdependent sequential steps to achieve meaningful results according to the principles of DSR. The research gap was examined with the means of a literature review and research as well as 15 structured interviews, 138 participants in a structured questionnaire, 13 for data attributes examined BIM projects and a reviewing expert panel of 12 proven experts on the field of BIM and FM identify interferences [93]. A project was taken into consideration, namely a test project of a public client in Switzerland to identify the "how to Knowledge" approach and build an optimum scenario in terms of investment, use of resources and efforts for applicability.

3.2. Main principles of framework

In this context, the term conceptual framework is defined as "a network of interlinked concepts that together provide a comprehensive understanding of a phenomenon. [These] concepts […] support one another, articulate their respective phenomena, and establish a framework-specific philosophy." [96] (p 51)

There are three important aspects that are considered in this context, which are drawn in Figure 2, the conceptual framework cube. These include whether existing applications with FM content are used, whether information management via BIM is used ("BIM") and whether information for the life cycle is structured early in the construction project. The x-axis represents the application/use of FM, the y-axis the structuring of information and the z-axis the application/use of BIM. In the interest of clarity, the two rear segments D and H, which are not or only partially visible, are inscribed at the front.

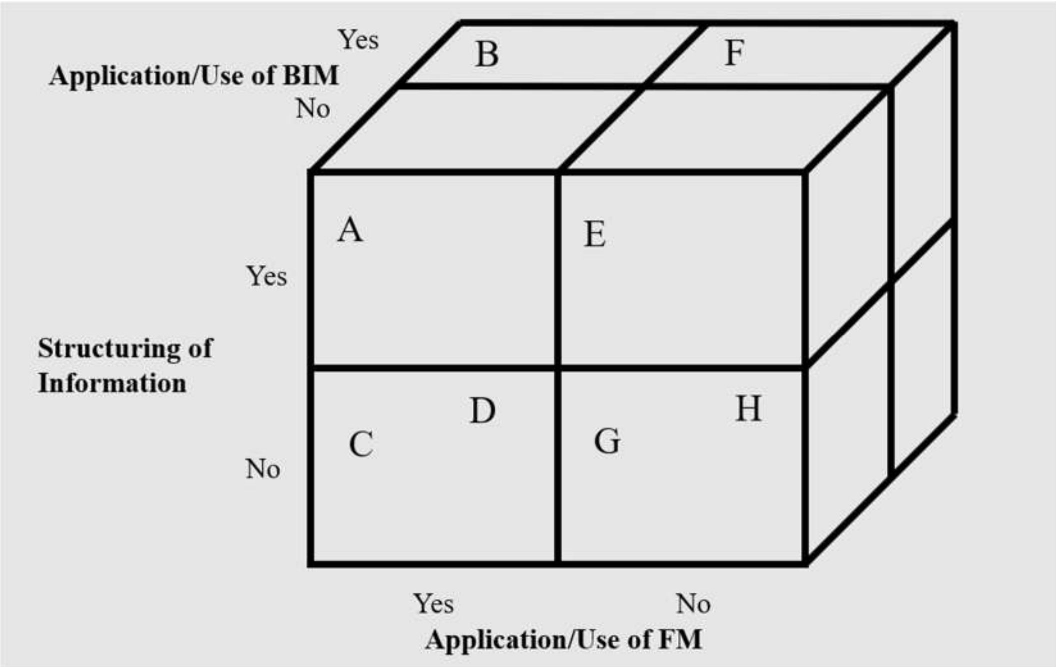

Figure 2. Conceptual framework cube (own illustration).

This cube generates eight situations to be distinguished. The following table briefly explains the individual segments of this conceptual framework cube. The size of the segments does not correspond to the real distribution of the distribution and initial conditions of the respective segments and their but serves for simplified illustration purposes only.

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Table 1. Conceptual framework cube segments.

Segment	Description	Characteristics
A	Non-BIM Case	Information structuring takes place but not with BIM with structured data used in FM.
B	Best Case	Existing data structure which is generated with BIM and handed over to FM
C	Planning-Error Case	No data structuring and generating for the later use of the asset which applies FM
D	Unstructured Case	Data is not commonly structured but generated by multiple stakeholders and handed over in a non-effective way
E	Inefficient Structuring Case	Data structuring, but neither efficient application in BIM nor handover in FM
F	Planning Efficiency Case	Data structuring is done and applied with BIM, but no use or handover to the FM.
G	Worst Case	No data structuring, no generating, and no use in the FM.
H	BIM Case	BIM is used, but not applied efficiently as no data is not structured nor handed over.

Consideration can only be given to segments in which either all three criteria are met ("Best Case", Segment B), data structuring is met and there is further use by means of BIM or later in the utilisation phase by means of FM. These would be the cases "Non-BIM Case", Segment A or "Planning Efficiency Case", Segment F. The other segments are excluded for the further investigation. Segment E "Inefficient Structuring Case" should be mentioned here, in which data is structured for the project, but neither used further with BIM or in the operational phase. This represents a theoretical case.

Based on the DSR principles of testing and evaluating, the dimension cube and the outcomes of questionnaire and interview, a fundamental conceptual framework based on a use case is necessary. The aim is to iteratively achieve a result that can be reused as often as possible with as little effort as possible. A framework is hereby defined as *"a semi-complete application. A framework provides a reusable, common structure to share among applications. Developers incorporate the framework into their own application and extend it to meet their specific needs. Frameworks differ from toolkits by providing a coherent structure, rather than a simple set of utility classes"* [97] (p 4). A framework is a basic functional structure, neither an application nor a system [98]. According to [99] (p 43) a conceptual framework is the argumentation why *"the topic of a study to its often intersecting fields, why the methodological approach used to explore that topic is valid, and the ways in which the research design is appropriate and rigorous"*.

In questionnaire and interviews, the statement manifested itself that the FM only needs a limited amount of information to be able to operate an asset effectively and efficiently. The following attributes can be named in concordance, which must be defined in an order of the client for the intelligent data structuring of smart applications (Table 2). This was done according to a value-in-use analysis and the evaluation of the time of ordering.

Table 2. Data attributes for intelligent data structuring of smart applications for FM.

Data attributes	**Unit**	**Order Phase**	**IFC Attributes** [100]
Volumes	m^3	First Planning Steps	IFCQuantityVolume
Areas	m^2	First Planning Steps	IFCQuantityArea
Units	pcs	First Planning Steps	IFCQuantityCount
MEP details	Text	First Planning Steps	Depending on device, but SharedBldgService
Type of material	Text	Engineering Services	IFCMaterial

3.3. Phases and roles of framework

Before elaborating the conceptual framework, it is useful to distinguish the phases and the respective roles involved. In Figure 3, the time is plotted on the x-axis and the respective role with its usual entry and exit in the project on the y-axis. To ensure international comparability, the roles and phases used in the charts correspond to those of the ISO 19650 series of standards. Neither phase durations nor importance of roles nor influences of roles have been scaled.

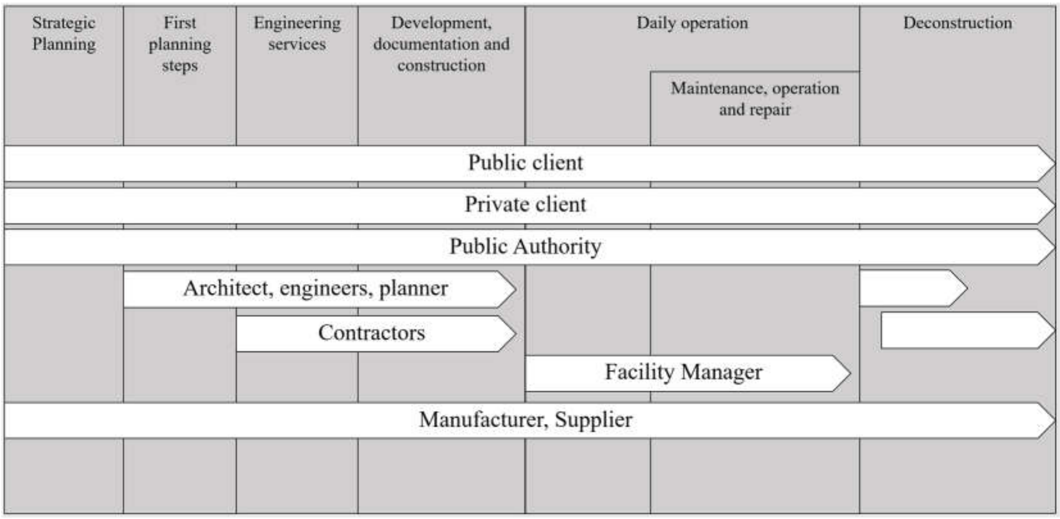

Figure 3. Conceptual framework phases and roles (own illustration).

It is evident that some roles are involved throughout the life cycle, such as the client and public authorities. Others, such as contractors, are involved in short phases of the asset life cycle, such as the first planning steps, development, documentation, and construction. At a later stage, the role of the contractor or architects, engineers, planners respectively may re-emerge when the asset is dismantled. In the case of deconstruction, it is (usually) necessary to commission these groups of experts due to the general conditions of building law, the necessary expertise and diligence

For the incremental development of the conceptual framework, Figure 4 was used as basis to structure phases, data-carrying systems, and associated roles.

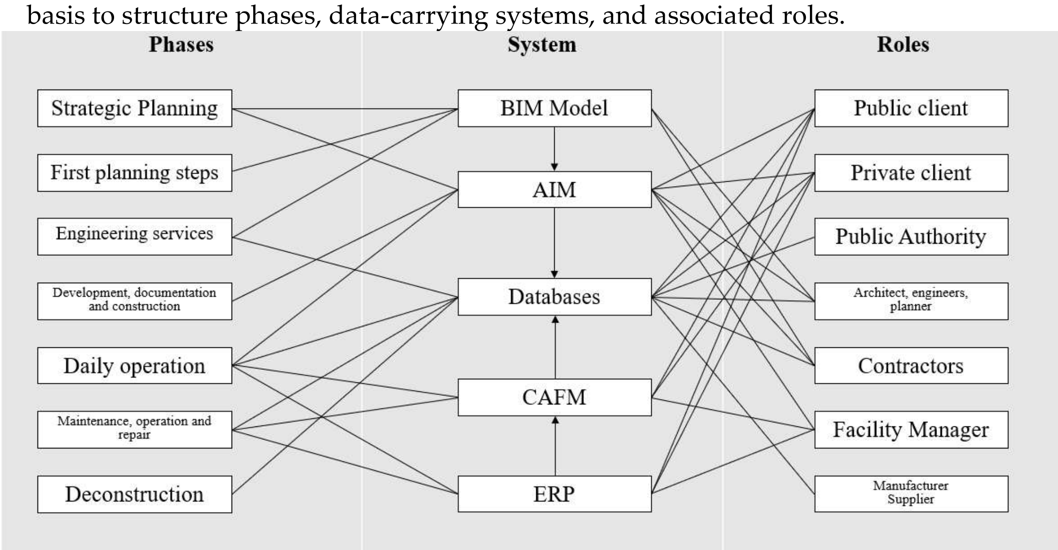

Figure 4. Conceptual framework connection phases, database systems and roles (own illustration)

Considerations were made as to which data-carrying system (middle column) is used in which phase (left column). It is assumed that the systems build on each other, i.e., the BIM model supplies information to the AIM, for example, which in turn supplies information to further databases. Similarly, from Enterprise Resource Planning (ERP) to Computer Aided Facility Management (CAFM), whereby the intersections are not completely clearly separable. These systems were then linked by the utilizing roles (right column).

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Figure 3 shows these dependencies. Phases and roles correspond to the specifications of the ISO 19650 series to enable international comparability.

Diverse stakeholders access different systems in divergent phases. Not everyone involved has access to all systems, such as manufacturers and suppliers who, as providers of information, will not have access to internal databases for security reasons, among others. They do not necessarily need this access for the contractual fulfilment of their tasks. Furthermore, the division into phases is a reason not every participant is involved throughout the entire life cycle of a project, such as architects, who are primarily included until the physical completion of the building including its handover.

3.3. Data sets and attributes of framework

Following, these attributes are plotted and link to the necessary data sets. This is implemented in Figure 5. This means that the attributes most often mentioned and supported by most experts from questionnaire and interviews were linked to the resulting products. For example, areas, volumes, units, and materiality are needed for three-dimensional visualizations. Temporal data such as warranty dates or operation times are not necessary here or are not displayed because they are of dynamic nature.

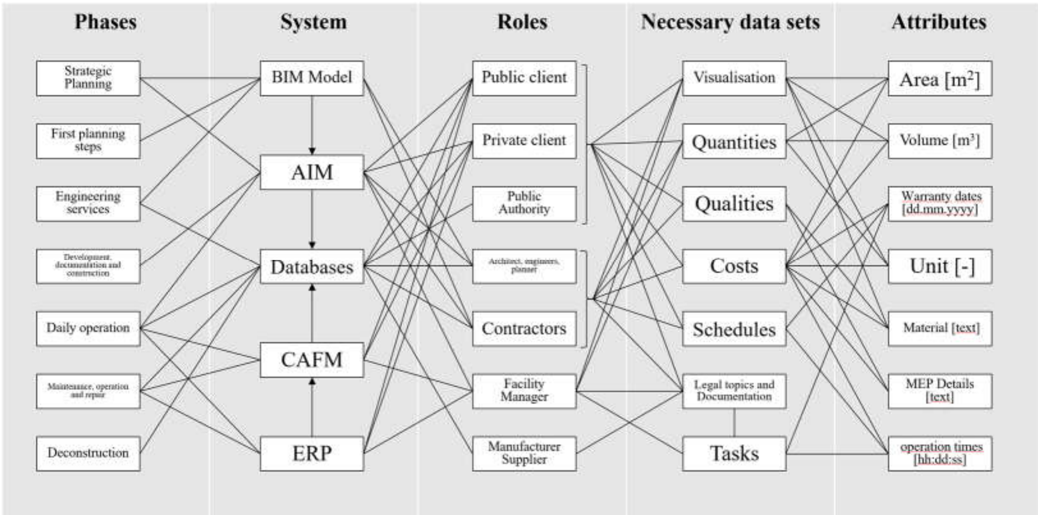

Figure 5. Conceptual dependencies and information models (own illustration).

Based on these dependencies, this can be represented for individual roles, such as the FM. If the by-lines are removed, the dependencies become significantly lucid. The dependencies and respective systemic foundations are shown in bold lines in Figure 6.

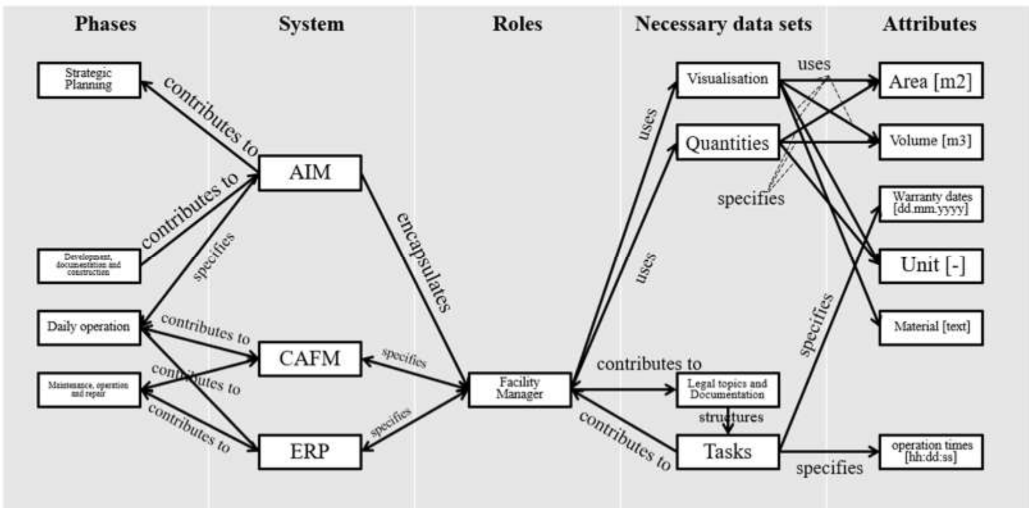

Figure 6. Conceptual dependencies and information models (own illustration)

Several points here can be elucidated which point to a certain regularity, when considering the facility manager:

- No attribute is referenced by more than four necessary data sets
- Only when determining the cost impact, all attributes are used, otherwise each necessary data set determines not more than four attributes
- Only one of the attributes deals with dynamic data that accrue during operation (operation times)
- Only one attributes deals with fixed dates (warranty dates)

4. Discussion and verification

In this context, it is also obvious that the facility manager must access more than one data-carrying system in his function and that there are tendencies towards redundancies. Considering the other points of the evaluation, this is also noticeable for the other roles.

- Certain data-carrying systems become redundant during the life cycle of the asset
- Private and public clients as well as public authorities have the same requirements regarding necessary data sets.
- The attributes are existent, the accuracy of the attribute's changes. It reaches a peak in the execution like a Gaussian curve and then decreases again (slightly).
- Data attributes need to be ordered at these stages to enable maximum benefit for the establishment of smart applications.
- Most importantly, clients shall order areas and volumes in the corresponding accuracy.
- Data structuring does not exonerate any party from their duty of care as well as from the application of the necessary DG.
- A high applicability does not necessarily imply a high existence of the data attribute or the data field content in the respective phase.
- The time of ordering data does not necessarily correlate with its provision.

A data carrying application ("App") could provide the client with an automated tool to which the selected Asset Information Requirements (AIR) generated from the corresponding Asset Information Model (AIM) can be applied. These Information Requirements (IR) of the client contributes to the BIM Execution Plan (BEP) of appointed companies. For this purpose, it is necessary that the requirements from the AIM system can be automatically transferred into machine readable attributes, which ideally, are IFC parameters. The following flow chart in Figure 7 illustrate this.

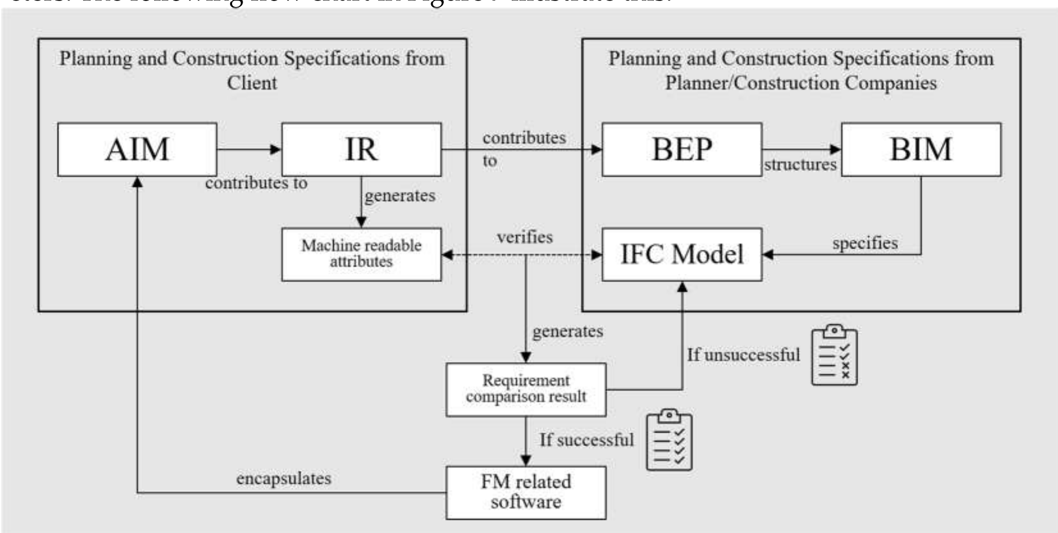

Figure 7. Flow chart of Application procedure (own illustration)

This verification from the given "Planning and Construction Specifications from Client" regarding the conformity of the developed implementation specifications of the planners and construction companies can be solved by means of this application.

5. Conclusions

This research work contributes to the current discussion by presenting a possible conceptual framework for intelligent data structuring. This work is based on academic sources which, due to the growing popularity of the topic, represent wide-ranging and sometimes divergent opinions. The selection of sources was made without prior evaluation of the content but can only represent a limited part of the existing literature in the field of BIM in the construction industry. Despite the extensive number of publications in the field of research, a purely quantitative evaluation is not expedient, as this would require a representative selection of sources. Due to the intense research activities in this field, this is an unmanageable challenge that would not be scientifically justifiable. For this purpose, an iterative system of research was applied in which advantages and disadvantages were consistently considered.

In this work, the status quo of the construction industry regarding information management and BIM was discussed as an important basis to elicit precise, targeted solution options. It is important to understand that due to construction-specific, national, transnational, and international differentiations, there are different interpretations of the respective topics, which are first juxtaposed. This was contrasted with the approaches of Industry 4.0 to evaluate potential solutions. For this purpose, interviews were conducted with experts, specialists were surveyed by means of questionnaires and 13 projects in the BIM context were evaluated. In general, it must be emphasized that no specific method of BIM was evaluated, but always the finished result, usually a three-dimensional model with stored data. Expressed differently, it was not a question of evaluating the "how", i.e., how the data input into models and/or related databases is done, but the "what", i.e., what is possible with the data input from models and/or related databases.

From this, a conceptual framework was constructed on how information requirements can be created in the initial phases of a project to enable smart applications, here using the example of a meeting room booking. For this purpose, fundamentals were defined, and existing terms were refined. For the classification of this conceptual framework, it was considered in the context of a prevailing, exemplary, and ideal-typical project management of construction projects. Based on this, the conceptual framework was transferred into an application which is possible for the purpose of the work and the differences and necessities in the management were shown.

These smart technologies and applications from the Industry 4.0 framework can help the construction industry, which is on the digital leap, to use the arising data in a targeted manner. However, it requires a joint, structured, and long-term commitment to enable smart applications over the life cycle of an asset by intelligently ordering the correct attributes in the corresponding phase.

6. Patents

Author Contributions: Conceptualization, A.A.W.; methodology, A.A.W., J.B.; validation, A.A.W, J.B., P.P; formal analysis, A.A.W.; investigation, A.A.W.; resources, A.A.W., J.B.; data curation, X.X.; writing—original draft preparation, A.A.W, J.B.; writing—review and editing, A.A.W, J.B., P.P; visualization, A.A.W.; supervision, J.B., P.P.; All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflict of interest.

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