# DIGITIZATION FOR INTEGRATION: FRAGMENTED REALITIES IN THE UTILITY SECTOR

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The construction industry and its reform agendas commonly assume that digitization of a construction asset's life cycle also integrates its stakeholders. Behind this lies the premise that stakeholders reduce ambiguity and create consistency by using software that operates on the basis of shared and uniform knowledge. To explore this premise, this study identified the knowledge bases - data standards and modelling protocols for engineering software - that distinctive underground infrastructure owner's use. To this end, we analysed a utility engineering consultancy that registers and processes asset data of twelve major utility owners. We observed their utility information managers and studied their asset management guidelines. We used two utility taxonomies from literature to compare identified digital modelling standards. Subsequently, we used literature about modelling standards in digital practices to argue how selected examples of divergent digital models hamper uniformity. We conclude that digital reality models may also differ and thus confuse, fragment, and ultimately delimit collaborative digital practices. This insight stresses the relevance of defining shared domain understanding to facilitate the uptake of software for collaborative engineering practices. It stimulates construction improvement agents to consider this important notion of shared digital realities in their debates about achieving integration by 'going digital'.

Keywords: digitization, fragmentation, integration, standardization, utility sector

## INTRODUCTION

Building Information Modelling (BIM) advancements drive state-of-the-art engineering and problem-solving in the construction industry. Its implementation is a much-discussed topic in literature and policy documentation (e.g. Bradley *et al*., 2016; Lu *et al*., 2015; Pauwels *et al*., 2016). One of the main steps in converting to this 'BIM paradigm' is through digitization, which involves the development of 'digital twins' of construction assets. A general belief in the construction industry - for example, visible in industry reform agendas - is that digitization of the information relevant to the construction asset's life cycle further integrates stakeholders. The argument follows the implicit logic that ambiguity will decrease and consistency between exchanged information will increase when stakeholders all accept and implement one uniform knowledge base for their (BIM) software. Taking this for granted, however, may cause 'digitization hubris'.

The problem with this ideal perception that digitization stimulates integration of the fragmented supply chains in the construction industry is that it ignores that digital practices themselves are also fragmented. Software interoperability and information integration issues (Lu *et al*., 2015) complicate this integration of fragmented practices. Turk (2001) describes a typical way in which construction-IT developers capture

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practitioners' realities. He argues that standardized data formats and structures help to achieve integration under the condition that these are accepted and represent practitioners' shared perceptions of realities. In addition, Gustavsson *et al*., (2012) and Samuelson and Björk (2011) indicate that a lack of consistency in and acceptance of the adoption of standards creates a barrier to the realization of integration.

The lack of consistency in and acceptance of the adoption of standards has led to the phenomenon of, drawing on Timmermans and Epstein (2010), "a world of standards, but not a standard world". This phenomenon is also typical for the architecture, engineering and construction (AEC) industry, where nations, organizations and even individuals have been developing digital (BIM) standards in a rather fragmented and self-centred manner (Azhar 2011).

Although existing literature argues that consistency in and acceptance of standards is a prerequisite in achieving integration through digitization, this suggests that a professional paradigm is able to develop a unified and accepted standard. This study verifies whether such a unified and accepted standard is developed in practice. In specific, it explores the digitization practices in the utility sector to understand the extent to which digitization leads to uniform digital practices. We identified and assessed digital standardization practices in a utility engineering consultancy and show that the industry currently uses various standards to model the same utility asset information. Consequently, we argue that implementation of digital practices may lead to digital information but that this does not necessarily result in a common and accepted set of uniform practices. We show that the existence of different digital realities hampers the integration of stakeholders.

The remainder of this paper is organized as follows: we first describe related literature about digitization and standardization. Second, we present how we used a case study to compare standards in practice. Third, we present findings by elaborating on selected examples of differing standard descriptions of an asset object. We compare the findings to literature before we draw our conclusions.

## Related Literature

The use of technology in construction projects can improve the inter-organizational communication, cooperation and coordination (Adriaanse *et al*., 2010; Peansupap and Walker 2005). In the process of using such technologies, the construction industry digitizes construction assets by defining concepts, attributes, and their relations (El-Diraby and Osman 2011). Digitizing asset data is realized through applications like BIM (Bradley *et al*., 2016). Methodologies should be developed to facilitate exchange and communication between such applications in order to streamline work flows. Currently, this happens through the development of semantic web ontologies (Pauwels *et al*., 2016) and asset data modelling standards such as the Industry Foundation Classes (IFC) for BIM software (Turk 2001) and CityGML for geospatial software (Open Geospatial Consortium).

Standardization is critical to facilitate communication between different stakeholders in a fragmented industry - like the architecture, engineering and construction (AEC) industry (Howard and Björk 2008). Standards for representing construction data, such as IFC and CityGML are gradually accepted and used as the predominant way to exchange data between engineering software. However, common data formats for major types of infrastructure projects, such as transport, utilities or environmental projects (Bradley *et al*., 2016) are less developed.

The aim of standardization, in general, is to capture realities and construct uniformities across cultures, time and geography on the basis of agreed-upon rules (Timmermans and Epstein 2010). These agreed-upon rules are thereby captured in standards, which, on their turn, emerge from many fields (Bowker and Star 1999; Timmermans and Epstein 2010). The types of standard relevant to this study, are digital modelling standards. Such standards are also referred to as 'ontologies' (El-Diraby and Osman 2011). In computer science, ontologies are used in the process of knowledge elicitation - i.e. the process and output of reality modelling. In this process, knowledge is modelled in artefacts such as domain ontologies. Ontologies describe the world as seen by a group of people at a certain time according to a school of thought that is based on a set of fundamental propositions or world views (El-Diraby and Osman 2011). Once adopted and shared amongst practitioners, they represent domain knowledge in a unified, simplified, and consistent way.

Capturing realities through digital modelling standards - i.e. ontologies - for the fields in which digitization emerges requires thought about phenomenology - a branch of philosophy that deals with how to take things for what they are and what it means 'to be' - and hermeneutics - a branch of philosophy focussing on interpretation. Intention and interpretation are relevant when capturing realities, because their meanings can be shaped both by the authors and users of standards. Once explicated in a textual form realities can, therefore, have several plausible interpretations (Turk 2001). Likewise, Lampland and Star (2009) argue that it is not surprising that standards have many possible antonyms, given the range of possible meanings packed in a term.

When digital modelling standards are not adopted in digital practices, this may hamper construction IT adoption. In their adapted model of IT adoption - based on the unified theory of acceptance and use of technology, the theory of planned behavior, and the technology acceptance model - Adriaanse *et al*., (2010), have identified that differences in working practices, resources and objectives hamper successful adoption of IT. The existence of differing work practices also impacts digital modelling practices. Co-existence of multiple practices, may, for example also result in situations where practitioners use distinctive digital modelling standards to model an asset. As a result, adopted IT may use distinctive knowledge bases, and therefore show little uniformity in knowledge representation. Therefore, we hypothesize that using IT, and developing standardizations, does not automatically enable adoption and integration of IT users. The different digital realities can explain why adoption and use of IT in AEC industry are not always as effective and efficient as they could potentially be (Hjelt and Björk 2006; Sulankivi 2004).

To date, literature seems to have focussed on proposing a standard for a certain domain (e.g. El-Diraby and Osman 2011) or argue that standards should be developed to achieve integration (e.g. Gustavsson *et al*., 2012; Samuelson and Björk 2011; Turk 2001). It does not, however, focus on the multiple standards - and as a consequence realities - that co-exist as a result of varying work practices. Limited attention is given to the impact of different realities on the successful adoption and integration of digital modelling practices. In light of shit research gap, this study observes the use of standards and IT in the AEC industry and seeks to provide the first evidence for our hypothesis.

## RESEARCH METHOD

Different standards of reality, as a result of varying work practices, have received limited attention in literature. Therefore, we considered an exploratory research approach most appropriate. We conducted a qualitative case study to collect data and gain insights in the topic investigated (Yin 2014). In this case study, we identified and compared the different standards used in the construction domain. More specifically, we decided to focus on a domain in which BIM technologies and standards are not adopted on large scale. The utility sector is a good example of such a domain and was therefore selected. We studied how standards and data protocols have been used in a Dutch utility engineering consultancy company. This company registers and processes utility data of twelve major utility owners, being our unit of analysis. The twelve utility owners cover the disciplines of water, gas, electric, telecom and district heating, where several utility owners represented multiple disciplines. As such, each utility discipline was covered by three utility owners.

The data collection approaches used in our case study include observations of work practices and study of asset management guidelines. To this end, we observed seven information managers whose daily task was to model underground networks. During the observations, the information managers showed and explained how utility owners store their realities in digital environments. While keeping notes on this, we had dialogues in which they explained their asset management work routines.

We also collected asset management guidelines from six utility owners that were used by the information managers as a guideline to verify data that surveyors and engineers modelled. We found international, national, and organizational standards. Asset management guidelines from the other utility owners were either not available or made accessible due to privacy reasons.

The elicited realities from practice were analysed in a two-stage process: (1) qualitative coding to abstract and compare the standards and guidelines, and (2) identifying differences or similarities between the elicited realities.

To abstract and compare the standards and guidelines, we used qualitative coding (Saldaña 2015). El-Diraby and Osman's (2011) typology of infrastructure objects was used to compare the various concepts and attributes in the standards that we found. This typology distinguishes between component level, subsystem level, and system level objects and captures, for example, spatial, dimensional, and material attributes. To this end, we identified how various asset owners of underground infrastructures describe and store their 'realities' in data standards and protocols.

After assigning objects to these various levels and attributes, our next step was to identify differences or similarities between modelled realities. For this, we used a typology from Gasevic *et al*., (2009) that essentially describes three elements of an ontology: (1) taxonomy and hierarchy, (2) vocabulary, terms and names, and (3) semantics: the linguistic meaning of the representation.

After identifying similarities and differences, we selected examples to explain how standards, albeit digitized, are still fragmented. This serves as first evidence for our hypothesis that using digital systems, and developing standardizations, does not automatically enable adoption and integration of IT users.

## FINDINGS

Our findings show that modelled realities used by information modelers were represented in: (1) international, (2) national and (3) organizational standards. The case study, both through observations of the work practices and study of asset management guidelines, reveals that, for example, each utility owner prescribed her own asset data registration standard, based on their own work practices. According to the modelers, the organizational standards were used more frequently than the international and national standards. Since most examples follow from these organizational standards, these will be elaborated on below.

The modelled realities represented in the organizational standards describe a comprehensive set of utility asset data. To this end, we found around twenty to forty infrastructure objects within a single reality, dependent on the type of utility discipline. Captured realities within the telecom discipline, for example, covered around twenty objects, whereas realities from the gas discipline covered up to forty objects. Most of the infrastructure objects found belong to the component level of El-Diraby and Osman's (2011) typology of infrastructure objects. We also found extensive lists of attribute information for the infrastructure objects at hand. Within elicited realities from the electricity domain, for example, up to fifteen attributes for the component level object 'kabel' (cable) were found. Within this example, spatial and dimensional attributes were, amongst others, included. A comparable number of attributes was found for other infrastructure objects.

When comparing the abstracted realities, we found that in general similar objects and attributes were captured in the standards. Standards include comparable component, subsystem and system level objects. This finding also applies to the type of attributes captured. However, a more detailed comparison between these standards - i.e. realities - shows differences. Following the typology of Gasevic *et al*., (2009), three illustrative differences are presented in more detail, while briefly noting others:

First, one example of a taxonomical difference is visible when comparing three standards of the telecom discipline. These standards use subsystem level and system level objects to model their telecom network in the following two ways. First, two standards use subsystem level objects to model their coaxial and fiber network as individual subsystems. Their main telecom network, including both the coaxial and telecom network, is modelled on top of the taxonomy at the system level. Second, one standard models both the coaxial and fiber network on the subsystem level as one main telecom network. The particular network type here is specified as an attribute of the subsystem object, i.e. the main network.

Another taxonomical difference, for example, is visible within the modelling of the object 'station' (station) when comparing three standards of the gas discipline. Where two standards model a station as one single component level object and define its type (internal, external) at the attribute level, one other standard defines the type of station already at the component level object. In total, we found around six taxonomical differences.

Second, an example of the way in which realities are modelled with a different vocabulary is the similar use of the words 'meting' (measurement) and 'nauwkeurigheid' (accuracy) when comparing two standards of the electricity discipline. Both standards use these words to describe the type of measurement of coordinates (either analogous or digital) in order to estimate how accurate the coordinates of component level objects are.

Another notable difference in use of vocabulary, for example, is the similar use of the words 'ligging' (area) and 'locatie' (location) to describe the x and y coordinates of a component level object. Differences in use of vocabulary were found to be most frequent, compared to the other types of differences in ontological representation. In total, we found around fifteen differences of the way in which realities are modelled with a different vocabulary.

Third, a semantic difference in the elicited realities is the ambiguous meaning of the word 'uitvoering' (implementation). The word is used to describe various characteristics of objects on mainly the component level. Six standards across the telecom, gas and electricity discipline, show the use of the word to describe divergent characteristics such as diameter, manufacturer, material type, and installation type. This difference was even found in individual realities of the gas discipline. In addition, in three standards of the electricity discipline, the word is used to describe multiple characteristics at once, including manufacturer, material and diameter.

Other examples of semantic differences include the ambiguous meaning of both the words 'sort' (soort) and 'type' (type). Similar to 'uitvoering' (implementation), these words are used to describe various characteristics of objects, being mainly the installation type and material type. In total, we found around eight examples of semantic differences.

Findings show that assets were modelled in standards for international, national and organizational communities. There seems to be a favored use of organizational standards defined by utility owners, rather than international and national standards. Moreover, the results show differences in ontological representations, since the elicited realities differ in their structure, use of terms and linguistic meaning of their representation.

## DISCUSSION

Many organizations nowadays digitize their assets (e.g. Bradley *et al*., 2016; Lu *et al*., 2015; Pauwels *et al*., 2016) through applications like BIM. Consequently, lots of different digital knowledge bases for software systems are created. Whereas it is believed that digitization of the information relevant to the construction asset's life cycle further integrates stakeholders, the existence of different realities - as represented in standards - has implications on the successful adoption of digital practices.

Realities in utility companies show differences in regional coverage and the ontological aspects taxonomy, vocabulary, and semantics. The realities, therefore, reveal different standards. This stresses the importance of the perspective of philosophy on integration. The utility owners studied create their own knowledge base, from their own perception on how to model the reality. Every utility owner, therefore, followed her own organizational standard. Moreover, these various standards reveal different realities and work practices. Literature argues that work practice differences and lacking acceptance of standards provide barriers to successful IT adoption (Adriaanse *et al*., 2010), but we add to this that, even with usage of locally accepted standards, it is not likely that an integrated digital practice emerges. This eventually limits the adoption of a sector-wide uniform digital modelling practice.

Differences in standardized realities cause confusion in a digital reality. One reason for this observation may be the fragmented nature of the AEC industry. According to Dubois and Gadde (2002), the AEC industry as a whole can be featured as a loosely coupled system, which stimulates the generation of variation. Because of this loose coupling, and therefore, fragmentation, it is not a great surprise that also fragmented realities are seen in digitization practices. A second reason may be the existing assumption in technology acceptance models on the effect of standardization. The study showed that without a shared and accepted standard, fragmented realities are likely to emerge. Whereas standardization is believed to be a driver of adoption and integration of digital practices, fragmented standards mainly cause confusion and thereby delimit collaborative digital practices.

This study contributes to literature as follows. First, this study adds better understanding to the dynamics underlying the studies that identify 'factors' for the adoption of technology and concludes that effectivity and efficiency of inter-organizational technologies are sometimes below average (Hjelt and Björk 2006; Sulankivi 2004). By going beyond assuming that digitization, via standardization, leads to integration, we provide evidence for the hypothesis that technology adoption in an emerging field goes in line with the definition of many standards. Based on this, we argue that such digital standards need to be unified and shared before being able to achieve collaboration benefits of information systems. This notion of 'varied standardization' should receive greater attention in technology acceptance models.

The limitation of this study is that it focussed only on the modelling practices in the utility domain. Although this is not representative for the full construction industry, it provides valuable lessons for other domains in construction where digital systems are not yet adopted by the larger community - e.g. in lower-tiers of supply chains and infrastructure domains. Therefore, we believe that the differences in realities found in this study are likely to learn the utility industry and the wider construction community about the importance of considering shared domain understanding in research as well as in industry digitization initiatives. Future studies can confirm these findings by extending our work with observation in other parts of the construction sector. Moreover, this study has only assessed digitization of construction asset data from an ontological perspective. Future studies should elaborate on the effect of other types of standards on the integration of stakeholders through digitization.

## CONCLUSION

This study postulates the hypothesis that digitization of the construction asset life cycle does not automatically lead to integration of stakeholders and more collaborative work practices. Our findings show that modelled realities are represented in international, national, and organizational standards. Although similar objects and attributes were captured in the various digital modelling standards, we show that these are 'standardized' in distinctive ways. A selection of examples from digitization practices in the utility sector illustrates differences in how domain knowledge is represented. The examples show how elicited realities differ in use of taxonomy, vocabulary, and semantics. This provides evidence for the existence of diverging realities. Such differences in modelled digital realities are likely to create ambiguity and may, therefore, fragment and ultimately delimit integration of digital practices.

The existence of the distinctive standard realities imply that the utility sector currently lacks a uniform digital modelling practice. This, in turn, limits the possibilities for IT developers to align information systems that exchange network data in a uniform way between network operators and contractors. These observed diverging realities seem less present in the facility and building industry. This part of the construction industry already established and adopted the object-modelling standard IFC.

This study confirms that various standards can co-exist in the utility sector. One reason for this may be that this domain is currently making the transition toward a digital practice for planning and managing their assets. This demonstrates that, while a sector moves toward implementing digital practices, this does not immediately lead to unification of practices and communication flows.

The example shows that initiatives that are aimed at stimulating 'digital collaboration', should be cautious in assuming that digitization immediately supports integration. We, therefore, urge practice in developing standards that capture shared ontological understandings. Such shared perception is a precondition for achieving integration though digitization in the fragmented construction sector.

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