AN EXPLORATIVE ANALYSIS OF EUROPEAN STANDARDS ON BUILDING INFORMATION MODELLING

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Abstract

Many standards for Building Information Modelling (BIM) have been published and more are being prepared. Practitioners and academics often struggle to understand the still-evolving relationships between them and how they can support day-to-day activities. In this research we collect data on BIM standards developed by CEN/TC 442. The standards are presented in a series of prototype online dashboards and analysed to study how they are related to each other and to the different aspects. The results can help standardisation bodies, professionals, and academics understand how key concepts are covered in standards, and explore how they are linked to other domains.

Introduction

The construction sector is known for its limited efficiency and productivity (McKinsey & Company 2017) and as well for its impact on our planet and its climate (UN 2017, IPCC 2018). Standardisation is seen as a means to improve productivity, supporting improvement of work methods and enabling collaboration between different parties and across projects (Yates & Murphy, 2021). One of the common examples in construction are the standards for design and construction drawings representation, now part of ISO 128 family "Technical product documentation" that date from the early 20's of the XX century (CEN, 2002).

With increasing digitalisation in the sector, and in particular with the increasing adoption of Building Information Modelling (BIM), many standards have been and are still being published by recognised standardisation bodies at both national and international levels, such as the European Committee for Standardization (CEN) and the International Standardization Organization (ISO) (Sacks et al. 2018). In Europe, a specific committee for BIM, called CEN/TC 442, was established in 2015, and to date it has published 16 standards and 3 technical reports. Just 6 outputs were developed by CEN/TC 442, while the others have been developed via the Vienna Agreement with ISO/ TC59/SC13, the international standardisation committee responsible for BIM.

However, despite the goal of standards to provide clarity in work processes, practitioners and academics often struggle to understand the still-evolving relationships between standards and how they can support their day-to-day activities (Howard and Björk, 2007). One issue is that some topics and definitions overlap in two or more standards which can confuse non-expert domain professionals in finding and referring to the correct standard to address their issues. Moreover, due to the increasing number of standards, standardisation experts find it challenging to keep track of the terminology and interactions, likewise, to identify possible gaps, or resolve contradicting directives across standards (NBS, 2020). Although different databases list the published standards (e.g. Czech Republic, BuildingSmart), inclusive overall analysis of these standards and their relationships has not been undertaken. In the scientific literature, various authors have reviewed BIM related standards from the generally narrow perspectives of their specific research directions (AbuEbeid & Nielsen, 2020; Binesmael et al., 2018; Ganah & Lea, 2021; Krawczyk, 2020; Kupriyanovsky et al., 2020; Li et al., 2020; Patacas et al., 2020). Most of these works analyse the logic of BIM standard use, or global review of BIM standards, giving some examples of usage, investigating deeper analyses of some particular industries, e.g. railways. However, none of the analysed studies provide a global comparative overview of the standards. Nor do they provide an accessible user interface which could give a complete picture and relationships in between the BIM standards.

The goal with this work is to support Architecture Engineering Construction and Operations (AECO) stakeholders in better understanding the European BIM standards landscape and their interconnections. The analysis also aims to identify gaps and contradictions between these standards.

To address this gap, this research proposes an online solution with interactive dashboards that may enable practitioners and researchers to discover, visualise and better understand the relevance of European standards for different AECO roles, phases and topics. Finally, the work points to future research actions focused on the update and improvement of results, as well as the development of usability tests to perceive how the presented outcomes relate to other users' needs.

Methodology

The work was undertaken by the EC3 Modelling and Standards Technical Committee during 2020 and 2021. The committee includes experts on standardisation who are lead authors of CEN standards or members of national standardisation bodies as well as researchers from across eleven EU members and their associated countries.
This research used a mixed methodology of both qualitative (review of standards) and quantitative (plotting tabulated reviews) methods. Firstly, a literature review was conducted which establishes the need for the proposed development and evaluation criteria. The relevant standards were then identified and collected in order to be structured in dashboards and analysed according to earlier defined evaluation criteria. The evaluation includes:

- Identifying the relevance of the standards for the various AECO stakeholders. The exploratory stakeholders selected include: Clients, Project Managers, Permit Agencies, Designers, Contractors, Facility Managers, Manufacturers, Software Developers;
- Organising standards according to the project phases they cover. The following phases are defined following the ISO 22263:2008 assumptions combined with the definitions of several other international plans of work (RIBA, 2020): Strategic Definition, Briefing, Design, Procurement, Manufacturing and Construction, Handover, Operation and Maintenance and Decommissioning;
- Identifying the relevance of standards according to specific BIM topics that are covered by CEN/TC 442 working groups. The exploratory topics selected include: Project Delivery, Data Exchange, Information Requirements, Terminology, Cybersecurity, Project Operation and Products;
- Identifying the different relationships between standards, especially normative references and informative references. Normative references are mainly documents published by ISO or the International Electrotechnical Commission (IEC) that are included in the normative text of a standard. While informative references can be any type of documents (standards, reports, articles etc) and they are included in the bibliography.
- Identifying the chronology of the different standards (year of first publication and year of latest version) to help understand their current formal relationships.

Some of this information was extracted directly from the standards such as the year of publication and references. Other aspects required a more in-depth analysis (e.g. to define the topics and phases covered) as well as knowledge and expertise of the researchers. For example, the research team explored how to define the relevance of any BIM standard to a given project role.
Each standard has been analysed by (at least) two experts and then validated by a third reviewer. Meetings have been arranged to discuss possible divergences to arrive at a consensus among the experts.
The data collected have then been compiled and explored through a first set of relationships graphs using Gephi (Bastian et al. 2009) and data visualisations using MS Power BI. These explorations have then been consolidated through a set of public online dashboards compiled using Microsoft Power BI which can be used for exploration and analysis. Finally, the dashboards have been presented to CEN/TC 442 experts to evaluate the relevance of the work in terms of structure and content which has been validated. These results have been published to make them available to the global AECO community. Figure 1 illustrates the methodology used in this paper.

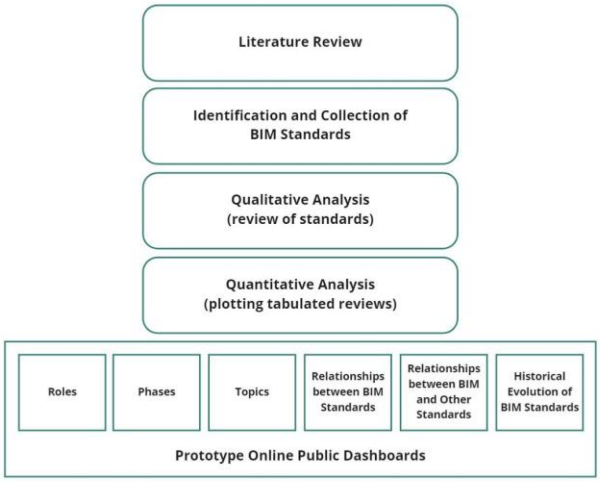

Figure 1: Overview of the methodology used in the present study

The remainder of the paper will describe the public online dashboards prototype followed by a discussion of the resulting graphs and their significant outcomes.
When an international (ISO) standard is adopted at CEN level it gets the prefix “EN”: “EN ISO” followed by the number of the standard. However, to facilitate readability of graphs, it has been decided to omit the prefix “EN” for international standards adopted at CEN.

Public Dashboards for the Exploration of BIM Standards’ Relevance and Relationship

A central output of this work is a holistic analysis of BIM standards with a prototype made available on a public website composed of 6 dashboards designed to ease the exploration of the standards for specific use cases. The website can be accessed at https://ec-3.org/BIM-Standards-Landscape-Explorer.html.

As an example, Dashboard 01 (Figure 2) enables users to select their role (1) in a project to retrieve the list (4) and count (3) of standards relevant to that role. Four levels of relevance of a given standard to a project role are considered in this research, to be selected by the user (2):

- *High*: the standard is essential for the given role to perform their day-to-day activities in using BIM in their company or project;
- *Medium*: the given role is not directly involved in the use of this standard, but an awareness may facilitate collaboration with other parties;
- *Low*: the given role is not directly involved in the use of this standard and its application has a marginal impact on the activity;
- *Not relevant*: the given role is not directly involved in the use of this standard and its application does not impact the activity.

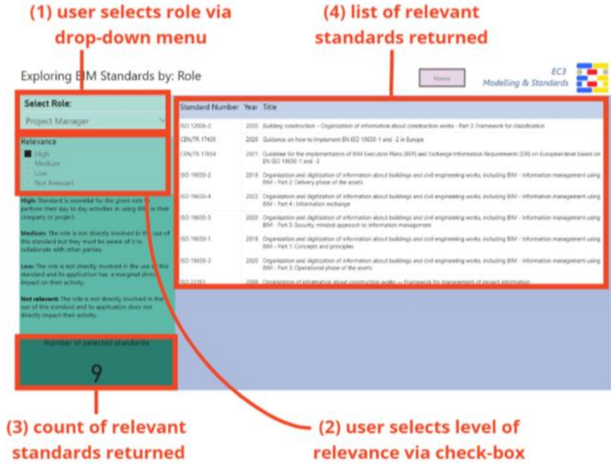

Figure 2: Dashboard 01 - Role focused, returns a list of related standards based on user inputs

Dashboards 02 and 03 have similar layouts and interfaces as Dashboard 01 but enable exploration around different criteria and do not have a relevance weight. Dashboard 02 enables the user to select the project Phase for which they wish to retrieve the list of related standards while Dashboard 03 enables the user to explore standards relating to a given BIM Topic.

An example of the second dashboard type is Dashboard 04 (Figure 3) which enables the user to explore relationships among the standards developed by CEN/TC 442, here referred to as "BIM standards". The relationships (1) in this case are presented in the form of a network graph (5). The weight of each relationship is also displayed as defined by the expert review. Three weights are used:

- High: the standard is a continuation of another standard and the two standards should be used together. Alternatively, the two standards might overlap in the scope.
- Medium: the standard covers similar topics and/or is part/shares same concepts and principles.
- Low: the standard covers similar topics. However, they can be used independently.

This weight definition aims to help users to better understand the strength of the relationship/association of different standards and how they should be used together. A count (4) and list (6) of standards is also displayed to the user who can furthermore set the timescale (3) of interest.

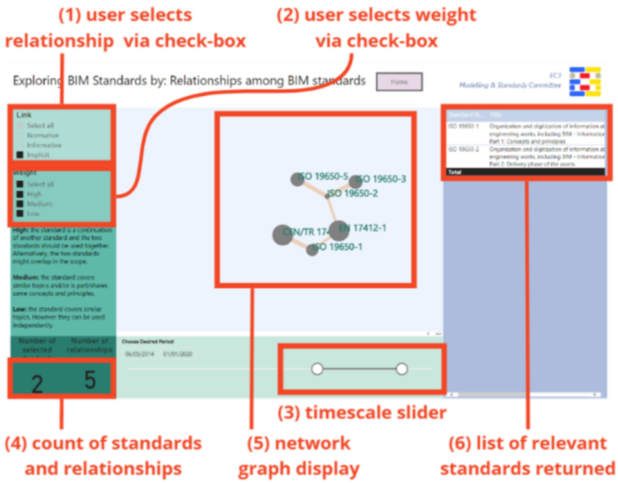

Figure 3: Dashboard 04 - Relationships among BIM standards, returns a network graph based on user inputs

Dashboard 05 extends Dashboard 04 by presenting the relationships not just among BIM standards but also to those which the BIM standards refer to normatively and informatively, also as a network graph. Finally, Dashboard 06 (Figure 4) illustrates the chronological evolution of BIM standards according to their first publication dates as a linear chart. The EN ISO 12006 series are shown in yellow, the EN ISO 29481 series in red, the EN ISO 16757 series in brown, EN 17549 series in purple, the EN ISO 21597 series in green and, lastly, EN ISO 19650 series in blue. The standalone standards are shown with the colour black.

Discussion and Result of Analysis

As noted previously, the dashboards can be used by standardisation bodies, professionals, and academics to explore BIM standards in relation to the defined criteria as well as their relationships.

The dashboards can be the subject of more in-depth analysis to identify patterns and gaps. To illustrate the value of the dashboard, the research team has conducted the following analyses:

- Patterns and recurrence in the relevance by roles, phases and topics.
- Relationship between BIM standards and non-BIM standards.

- Chronological sequencing of BIM standards according to their year of publication and references (normative or informative).
- Centrality analysis among BIM standards.
- Relationships of BIM standards clusters

The results of these analyses are discussed in the following subsections.

Relevance for users

One of the challenges of user relevance analysis was the lack of clear definitions of BIM(-related) roles in BIM standards, except for the appointing and appointed parties. This affected the judgement for defining the roles and their relevance to BIM standards. Therefore, the defined levels of relevance are subjective and based on the experience of the authors in the construction industry and standardisation.

An interesting result in the analysis of Dashboard 01 is that the standard EN ISO/DIS 29481-3 (under development) and EN ISO 16739-1 are mainly relevant to software developers. Another observation is that EN ISO 19650-1 is highly relevant to all roles in a project, but has lower relevance to manufacturers, permit agencies and software developers.

Relevance for project phase

The analysis of Dashboard 02 shows that all standards are relevant to all phases of the project, this confirms the fact that BIM is related to the whole lifecycle of assets. On the other hand, this highlights how project phase is not an effective way to search BIM standards.

Relevance for topic

The analysis of Dashboard 03 shows that the initial topics selected, and used within CEN/TC 442, for relevance review in the standards are well discussed in most of the standards analysed. This shows as well that the exploratory topics chosen are also not sufficiently discerning. For instance, “Data Exchange” is talked about in almost all the BIM standards. This confirms the difficulties often raised by users regarding the difficulty of getting into specific topics (Yates & Murphy, 2021), as for some topics more than 20 standards need to be applied (Dashboard 04). In contrast, some topics are more niche, for example, only EN ISO 19650-5 focuses on Security issues and protocols. These findings point out the need for a further level of granularity in the next phases of this project for topic relevance analysis.

Relationship among standards

This analysis of the network graph in Dashboard 05 (see Figure 6) shows that BIM standards refer (normatively or informative) to a range of standards in a range of domains including: Project Management (PM), Construction, Facilities Management (FM), Quality Management (QM), Information and Communication Technology (ICT), Industrial Automation (IA), Geographic Information (GIS), Health Information (HIS), and Other. In particular, the analysis shows that the standards in PM, Construction, FM and QM – which are more focused on traditional construction asset delivery and operation – contain little reference to “digitalisation” domains such as ICT, GIS, HIS and IA. The graph network clearly shows how the BIM standards – which are focussed on the digitalisation of construction asset delivery and operation – bridge those two domain groups.

Chronological evolution of BIM standards

This analysis (Figure 5) shows that the first BIM standards were published in the early noughties, including EN ISO 12006-2 and EN ISO 12006-3. However, most BIM standards have been published since 2019. This

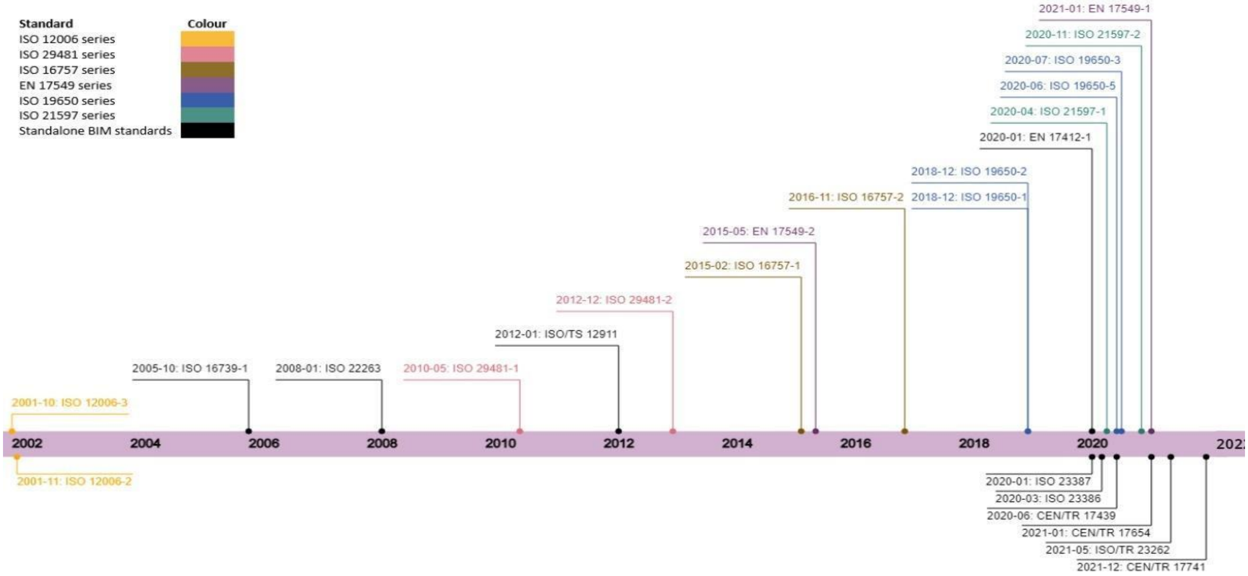

Figure 4: Dashboard 06 - Chronological publication of the BIM standards

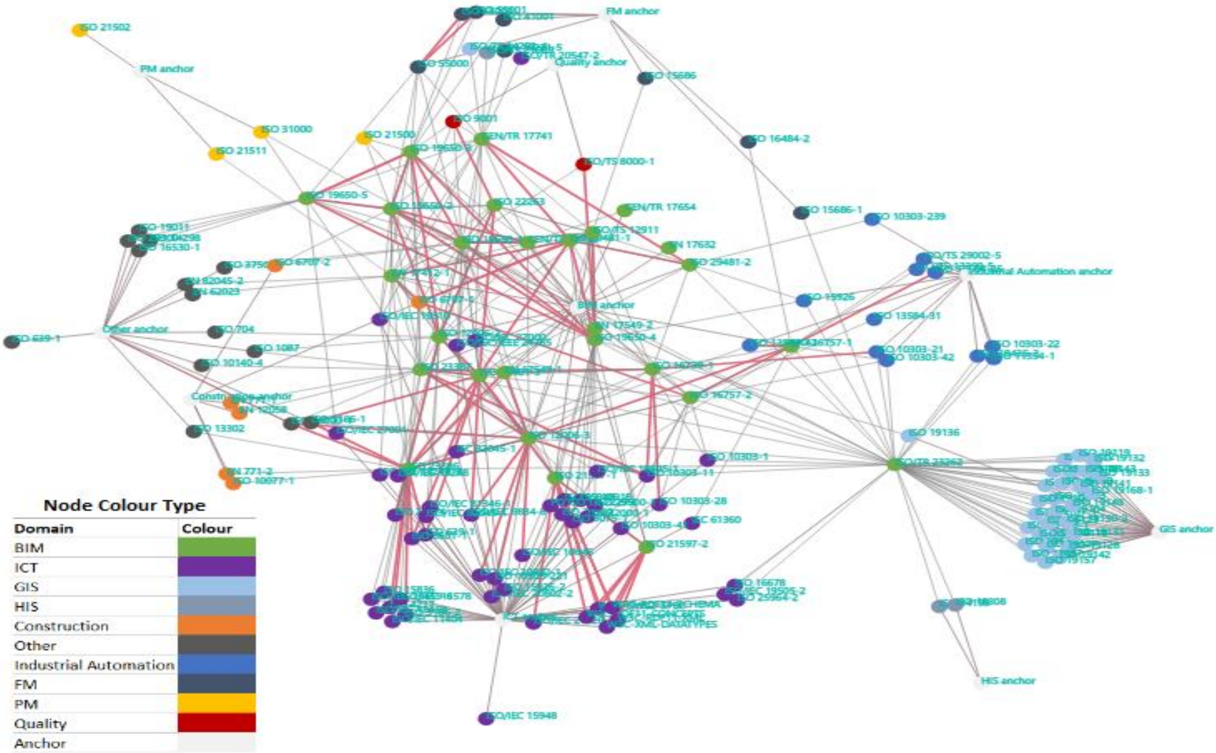

Figure 5: The full netwrok graph in dashboard 05

rapid recent progress is mainly driven by the fact that a dedicated CEN committee (CEN/TC 442) has been established on BIM in 2015 and therefore more standards have been published and adopted in the following years. This could have also been driven by the enhanced awareness of needs by AECO professionals to use BIM in their projects and the increase of BIM mandates across the EU. It is important to mention that standards are usually reviewed every 5 years, and this should not confuse the reader that might not be familiar with the standardisation process.

Network Analysis

Figure 6 shows the graph network of BIM standards from Dashboard 04. The graph contains 26 nodes (the BIM standards) connected by 108 links representing normative and informative relationships. An analysis of this graph can give some insights into which standards appear more central, how the BIM standards cluster around certain subjects and whether important relationships are missing.

Standard Centrality

Through network modelling in Gephi, degree centrality was leveraged to measure the relative influence of the BIM standards in the network. The in-degree centrality of a node (here, a standard) is the number of standards that refer to that standard. The out-degree centrality is the number of standards that standard refers to. Degree centrality is the sum of both (Yang et al. 2017).

The research initially considered all three metrics, but it was found that in-degree centrality and out-degree centrality were not reliable metrics for this graph because many standards were only recently published and older ones are likely to need to be updated to take account of the existence of these new ones. As a result, new standards tend to have high out-degree centrality but low in-degree centrality, and older ones exhibit the opposite characteristics. Focusing on degree centrality reduces the influence of the publication timeline (which will not be an issue once the publication of BIM standards settles).

The BIM nodes appearing in Figure 6, EN ISO 19650-1, EN ISO 12006-3 and EN ISO 23387, shown in red, have the largest degree centrality values at 19, 15 and 14 respectively. While this could be expected for EN ISO 19650-1, it is less so for the other two, especially EN ISO

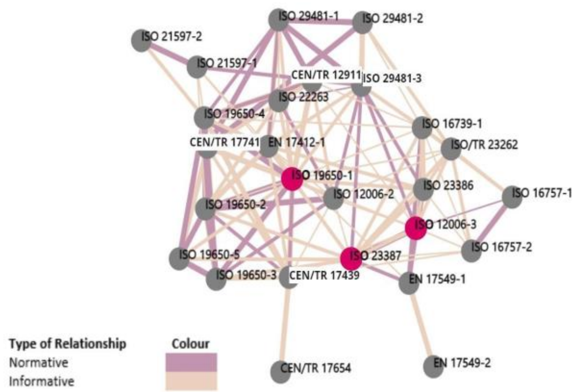

Figure 6: Network graph of BIM standards (from Dashboard 04) showing the standards with the largest degree centrality values (red).

12006-3:2016. Nonetheless, it should be noted that twelve standards have a degree centrality of 10 and above and the network has a diameter of 6, indicating that the network is quite tight.

Clusters

The analysis of a network graph can be done by analysing individual nodes or edges, but also by looking at clusters. Figure 7 reproduces Figure 6 with additional boundaries that the authors have identified as three clusters. The red cluster includes the standards that focus on the *Information Delivery Process* at a strategic and tactical level. This cluster builds around the EN ISO 19650 series. The blue cluster includes the standards that focus on the *Construction Domain Information Classification* (where 'Construction' should be understood in a broad sense*)*. This cluster particularly includes the EN ISO 12006 and EN ISO 16757 standards series. Finally, the green cluster encompasses standards that focus on the *Specification of Information Requirement*, addressing issues of a more practical nature. This cluster particularly includes the EN ISO 29481 and EN ISO 21597 standards series. It can be seen in Figure 7 how the first two clusters (red and blue) have comparatively few interconnections, especially normative ones. In contrast, the third cluster (green) is well interconnected to the other two. This seems consistent with expectations because specifying information requirements is a very important aspect of information delivery with BIM, and practically specifying information requirements in an effective and interoperable way requires the use of standard domain-specific classifications.

Conclusions

The research produced several dashboards where the European BIM standard landscape is structured and analysed to deliver understanding of their relations to roles, phases, topics, and themselves, as well as their chronological evolution.

It is evident that most of the BIM standards are applicable to all roles, however some such as ISO 29481-3 (under development) and ISO 16739-1 are mainly useful to software developers. This demonstrates that the knowledge of policies should be a key component of every AECO stakeholder, without considering BIM just as a domain for experts in technology.

The BIM standards are mainly applicable to all phases of a project as BIM covers the entire lifecycle. Thus, the project phase is not a highly discriminatory way to search BIM standards. However, in the future, the created dashboards should still be considered, as reference to visualise the applicable standards in the phases that AECO stakeholders are working on. Besides, BIM standards also tend to address several topics making it hard to follow. The standards analysis using high granularity lenses was identified as a key issue to be worked on further.

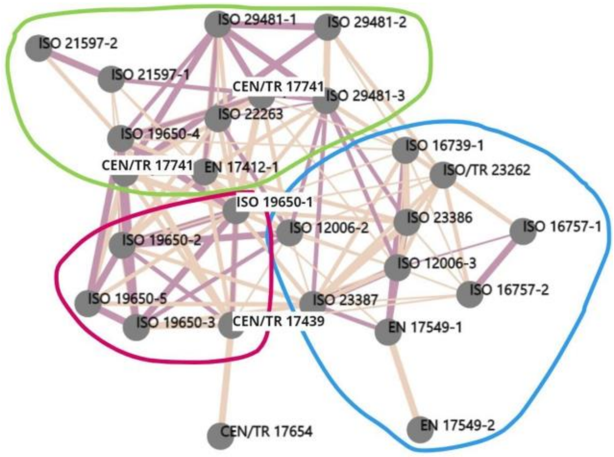

Figure 7: Clusters of standards in the network graph of BIM standards

Regarding the relationship of different BIM standards the paper shows that EN ISO 19650 series and EN ISO 12006 series have higher centrality relevance. When approaching the development of ISO 19650 series it was the intent of the drafting committee to set ISO 19650-1 as a key standard regarding BIM. To accomplish this, several previous standards were referenced, and they were integrated as background for concepts and principles. Thus, this standard and following parts have high centrality. This can benefit practitioners interested in ISO and CEN standards regarding BIM as they can consider those standards as a good starting point to understand the overall picture of the BIM standards landscape.

Moreover, BIM standards developed by CEN/TC 442 are linked to other domain standards on PM, FM, QM, ICT, IA, GIS and HIS, and often they function as connection between those domains.

Graphs have proved to be effective for discovering relations that were not obvious from reading the normative and informative references of published standards. Furthermore, the same allowed the identification of missing links between some BIM standards and ICT, Construction, FM, and PM standards. This is a topic to be explored further in future research.

These results can help standardisation bodies on the alignment and scope of future standards and can also help professionals and academics in the adoption and practical implementation of these standards.

The chronological evolution dashboard shows that the number of BIM related standards has grown significantly since 2019. Due to the constant evolution of standards, it is the intention of the group to maintain the analysis and published resources as new standards are developed in future. For these reasons, the group published the dashboards online in the EC3 website (https://ec-3.org/BIM-Standards-Landscape-Explorer.html) and plan to keep them up to date.

The researchers are also planning to evaluate the adoption of standards in industry to identify further needs and usage of the dashboards as a support for standards adoption.

Moreover, an empirical usability-based study will be performed to test how dashboards can facilitate awareness, comprehension and selection of relevant standards by the users. For example, the researchers will seek to add a dashboard that will merge multiple options (roles/phases/topics to be crossed referenced) and the revision of standards will be added to the chronological evolution.

Finally, it would be useful to perform further analysis using more granular topics on abstract wording and to develop word clouds showing chronological evolution of concepts to support standards update and the development of new standards.

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