A Proposed Model for Digital Transformation of Requirements Management in the Design of Healthcare Facilities

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Abstract:

The design complexity of healthcare buildings is ever-increasing, and due to the various codes, regulations, and client requirements that these buildings must comply with, the process of manual requirement management across the asset lifecycle becomes costly, labour intensive, error-prone and time-consuming. This paper proposes a theoretical process model for the digital transformation of requirements management for healthcare facilities. The model is titled "Automated Rule-Based Code Checking" (ARBCC). ARBCC process model is based on a comprehensive review of related academic work, commercial software, and government initiatives that investigated the automation of requirements management. ARBCC's approach is based on transferring the healthcare project requirements into rules that are machine readable, and can be checked using computer software, then use Building Information Models (BIM) to check if these rules have been correctly adhered to in the design of the healthcare facility at hand. The model consists of four phases: 1- Initiation: In which we identified and collated the rules and regulations of healthcare buildings in the UK. 2- Planning: In this phase, the extracted rules should be classified according to the RIBA stage, then the rules should be either extracted or written for each requirement, and the required BIM Level of Development (LOD) should be identified to check each rule. 3- Implementation: In this phase, the actual automated check of the created rules is performed versus the BIM model. 4-Assessment phase: In which the results of the check is analysed and any non-compliance is automatically reported using the compliance check software. This paper forms the initial theoretical base of an ongoing study that investigates the digital transformation of requirements management. The next phase of the study will be to implement the ARBCC model for a sample of the identified healthcare codes and regulations and analyse the findings.

Keywords: Digital Transformation, Requirements Management, HealthCare Design, BIM

1. Introduction

The architecture, engineering and construction (AEC) is an information-intensive industry by nature because every construction project requires the creation, dissemination, storage and analysis of extensive information about the built assets and spaces. The construction management literature has a lot of examples of problems associated with information management in construction projects with a recurring theme being poor management of design requirements throughout the project lifecycle (El Kharbili, 2012). For instance, the lack of common language between clients and design teams creates misunderstanding and ambiguity in identifying and defining client requirements. This ambiguity later requires more design iterations to clarify issues and more Requests of Information (RFI's) and if not appropriately managed, it ultimately involves re-designing or even re-constructing certain parts or systems of the building which is costly and time-consuming. This paper is part of an ongoing study to understand and address how digital transformation can support requirement management.

Building requirements come from different sources such as building regulations, codes and standards (Cheng et al., 2007), and these sources of requirements are often written in a way that is not machine-readable making it a mandate to check their compliance manually across all the teams and at all stages of the project. This manual check process is tedious, laborious, and prone to human errors. However, even with correct requirement identification, these requirements are often very complicated and require excellent communication between involved teams including architects, design consultants, construction engineers, subcontractors and facility management professionals. These teams are usually dispersed over a wide area of geographic locations creating problems with traceability and dissemination of the design information. Different teams also use different technology platforms to manage project information causing communication and collaboration to be inefficient. These issues have largely contributed to the construction industry's chronic problems of having cost overruns (Mahaney, and Lederer, 2010), severe delays (Tesch et al., 2007), and poor quality, and a lot of these issues are associated with the complexity of requirement management process through the building lifecycle.

The complexity of the requirements management process in construction stems from the need to collect different types of requirements from various sources. For example, functional requirements including client requirement that ensures the building will satisfy its business need, and stakeholder's requirements that ensure the building will be fit to serve its occupants and the broader community in the best way. Some of these requirements are sometimes contradictory (Eastman et al. 2009) and require good coordination and communication among stakeholders. Otherwise, it negatively affects the quality of the overall design (Bouchlaghem et al., 2004). Furthermore, requirement management involves collecting information in different formats including drawings, bills of quantities, spreadsheets, documents making it difficult to manage these requirements due to interoperability issues (Lee, 2012) between different systems used to manage information. The requirements also change during the project, as the design develops, it happens almost in all cases that the client would suggest some design changes, and these changes will have other consequences in other areas of building design. For example, a proposed space remodelling change by the client would require consequent changes in the Heating Ventilation and Air Conditioning (HVAC) and Mechanical, Electrical and Plumping (MEP) systems design in all remodelled spaces. These changes if not managed properly cause delays and increase the risk of rework in the project. Finally, the process of compliance check and assessment between the design/implementation and the original requirements span across all stages of building lifecycle (Kiviniemi et al., 2004), and it is done repetitively (Davis and Zweig, 2000). Lack of effective management of this information across the lifecycle causes inefficacies (Yu et al., 2005) in information access and compliance across stakeholders (Fernie et al., 2003).

In healthcare projects, the complexity of project requirements is even more significant in most of the cases (Cysneiros, 2002). This added complexity is caused by the different functional requirements that a hospital should satisfy (Doulabi and Asnaashari, 2016) including inpatient and outpatient functions, diagnosis and treatment, administrative, emergency, teaching and research and hospitality functions. Furthermore, modern hospitals use a vast range of diagnosis and treatment specialist equipment that adds another technical layer of design complexity on top of the normal building services such as HVAC, MEP, Information and Communication Technology (ICT) and safety and security systems. Historically, the compliance assessment/check for these requirements was done by using manual processes, because the information came in different formats and was mostly paper-based, this was time-consuming, yielded low-quality outputs of the information check (Jallow et al. 2014), and was resource intensive in terms of labour and time.

This paper deals with the emergence and vast spread of the concept of digital transformation that has become increasingly important in the Architecture, Engineering Construction, and Operations (AECO) industry especially in the last decade. At a global level, the unprecedented global challenges of ever-increasing urbanisation, climate change and open international competition called for new ways of designing, constructing and operating buildings and infrastructure (Zhang et al., 2018; Elliot, 2011). At a national level, digital transformation is considered a strong enabler for seizing the opportunities of the digital economy, building and managing the increasingly complex built environment, maximizing on the capacity and skills of the AECO sector workforce, and creating new business models based on emerging technology (Matt, Hess & Benlian, 2015). Building Information Modelling (BIM) as a digital transformation tool with its digital capabilities, collaborative philosophy, and systematic information exchange processes provided an excellent opportunity to automate the process of requirement compliance assessment, and Machine learning (ML) is another digital transformation tool that can be used for translating the complex requirements into rules that can be checked using the BIM model. Based on that, this paper will investigate an automation framework based on BIM that can be used to automate the process of requirements management and the opportunities and challenges associated with this in the construction of healthcare buildings.

2. Methodology

This paper presents a theoretical model for the digital transformation of requirements management in healthcare facilities. The model is mostly based on a literature review of related academic studies, industry reports, government regulations and commercial software reports. These sources covered different aspects of the requirement management, and automation, and formed an adequate base for an overall theoretical model. This paper forms the first phase of an ongoing study to investigate the digital transformation of requirements management of healthcare buildings.

The overall study will rely on Design Science Research (DSR) methodological approach. DSR is known to be an effective methodology in solving real-world problems and also contribute to the development of theories and models about these problems (Miah et al., 2014). Unlike other conductive research methods that require the test of an established theory using the collected data (Oyegoke, 2011), DSR uses an inductive approach to create models and frameworks that help in framing new theories. Hence, the assessment approach of DSR research is to test the resulting artefact and appraise its value using an iterative process that is very similar to the design process. Subsequently, further work is ongoing in the study to apply and test the framework using the identified UK healthcare regulations.

3. Theoretical background and related work

Historically, the construction industry, has always suffered from inadequate project management practises that caused construction projects to be over budget or delayed. In some cases, projects meet the budget and time constraints but fail to meet either the client requirements or the need of the ultimate users (Potts, 2008). For example, in the UK, Heathrow Terminal 5 project suffered from many problems by the start of its operation, these problems resulted in the cancellation of flights, and loss of passengers' luggage (Brady and Davies, 2010). The analysis of the causes of these problems indicated that many of them were due to lack of proper requirements management of the project throughout its design and construction phases. These inefficiencies in requirement management included insufficient involvement from project stakeholders, lack of adequate communication practices of client requirements, failure to incorporate continuous quality assessment in each phase of the building lifecycle, and poor risk management among design and construction teams. This highlights the need of innovative approaches to ensure the client requirements are incorporated within the project management of these complex projects to ensure the projects: First meet its constraints in terms of budget and schedule but equally important, to meet the client and user requirements.

According to the plan of work (PoW) of the Royal Institute of British Architects (RIBA), the first stage of any building construction should be stage 0, i.e. "strategic definition" (Architeture.com, 2019). This stage commences by defining the project's business case and core client requirements. The identification of the core client requirements at this stage is the start of the requirements management process. The Association for Project Management in the UK (APM) defines requirements management as: "The process of capturing, assessing and justifying stakeholders' wants and needs."(Apm.org.uk, n.d.) This definition breaks the process down into three stages: 1- Capturing, i.e. collecting different requirements from different stakeholders and governance bodies, and analysing the requirements to identify areas of conflict, gaps and overlaps. 2- Assessing the requirements and separating the obligatory regulations from the "good to have requirements". 3- Justifying that the actual building design complies with the final requirements as a baseline for the project. Each of these steps requires collecting and managing information from serval sources and in several formats which makes it a too complicated process to be done manually especially with the ever-increasing complexity of buildings (Pauwels et al., 2011), and the scarcity of resources including time and cost of skilled labour. That’s why the automation of requirement management has attracted a lot of interest from industry, government bodies and academia.

Following a survey of related work, the automated rule-based requirement management research which took two main streams. The first stream investigated the transfer of the text in the building codes, regulations and client requirements into machine-readable rules that can be checked using computer software. The second stream is concerned with investigating how to perform the actual checking of the automated rules with the aid of BIM. Following is an overview of the work done in this area in the two mentioned streams.

3.1. Translating the codes and requirements into rules

This research stream focuses on ways to transfer the text documents holding the codes, regulations and client requirements to a computer readable form to facilitate its automated check using the software. Today, the building regulations and client requirements are typically written in a way only understandable by humans (Jallow et al. 2014), and it also requires domain knowledge to interpret and understand its semantics due to its lack of clarity and sometimes its complexity. Several methodologies have been used to automatically interpret the regulations into a format that can be understood and used by computers which is called codification process. For example, a mechanism called RASE (Requirement, Applicability, Selection, Exception) can automatically transfer the text in the requirement documents into rules using the semantic web without the need of programming skills (Hjelseth and Nisbet, 2010) (Hjelseth and Nisbet, 2011). (Salama & Gohary (2011) developed a five-step approach with a preliminary model of transferring text into rules using deontic logic which is a branch of modal logic that is concerned with capturing logical features of a document. (Zhang & El-Gohary, 2012) Proposed the use of knowledge extraction to create rules out of the regulatory documents. This knowledge extraction involves the use of Natural Language Processing (NLP) and its associated techniques like phrase structure grammar (PSG) and dependency grammar (DG) for extracting information from complex sentences however the study was primitive and had a limited sample of text, and it was conducted using only one sort of requirements (Fire regulations).

Other research done in this domain used automated rule engines to compare the regulations with the model. Beach et al. (2013) extended the use of RASE by the use of the open source rule engine called DROOLS. The approach proposed to add metadata to the rules, and transfer it into a format understood by DROOL engine using a rule compiler then use the engine to determine if the rule is in scope for the project to be checked and second if the result of checking the rule a pass or a fail. However, the test for this approach was done using selected rules from the Building Research Establishment Environmental Assessment Method (BRAEEM) framework, and no extensive testing has been reported in this study. Nawari (2013) transferred the smart codes developed by the International Code Council (ICC) using language integrate query language (LINQ) to extract the information from the smart code efficiently, and then compare the extracted rule to the BIM model using ifcXML exchange format. The main theme of almost all of these efforts is that they all used a particular regulation and applied their proposed mechanisms to a small sample of the text of the selected regulation.

3.2. Preparing the BIM Model

After translating the codes, regulations and requirements to rules, BIM is used to check and assess if the building complies with these rules. However, to do that, the BIM model needs to be adequate for such a task. There are two main aspects of model preparation in order to be suitable for the check of the identified rules. First, data in the model should be in a suitable format to allow for the check, this format or view of the model is generally known as a Model View Definition (MVD) (Zhong et al., 2012). The second aspect is that the model view should include enough details about building spaces and assets to allow for the check, i.e. the Level of Development (LOD) should be adequate for the check. Following is a brief introduction to these concepts:

3.2.1. Model View Definition (MVD)

BIM contains large and diverse datasets about the building and its different assets. Consequently, there is no one rule or a ruleset that would need to check all the data in a BIM model at one instance. That is why to check a certain rule, a subset of the BIM model is extracted that fits the checked rule. This subset is called a Model View Definition (MVD) (Han et al., 1998). For example, a ruleset that is concerned with fire safety would require the areas of the model that are concerned with fire exits, fire safety systems and so on, and this rule would require a different view of the model from another ruleset that for example is concerned with checking accessibility requirements. The IFC (Industry Foundation Class) standard by BuildingSmart is the main model view definition standard. It was developed to allow for interoperability among different BIM authoring software (Liebichet al., 2006), and to allow a specific subset of building data to be extracted from the model to fit a particular need for this data. Therefore, IFC has provided a good ground for performing this automated rule check because it allows extracting views from the model that are best suited with the specific rule in hand.

3.2.2. Level of Development

Another BIM aspect that has a vital role in implementing a rule-based requirement management system is the level of development (LOD). LOD is developed by the BIMforum to identify the depth of information about assets that BIM model must include in different stages of building lifecycle (Solihin and Eastman, 2015). The LOD has two main categories; first, the Level of Information (LoI) that is concerned with the data aspect of the asset in the BIM model, and what details should be there about the asset in every phase of the building lifecycle. Second, the Level of Detail which is concerned with the geometry/graphical aspect of the assets in the model. Currently, there are five levels of LOD in industry, namely LOD 100 to LOD 500 in the US system (Solihin and Eastman, 2015). Each LOD has a full representation of the state of the data and geometry of the BIM model at a particular phase of the building lifecycle. This representation is usually identified in terms of its IFC parameters (Hietanen and Final, 2006). The importance of the concept of LOD for a rule-based system is that it makes it easier and quicker to identify which rules can be checked in which phase of building lifecycle according to the BIM model's LOD. For example, in a healthcare facility, a structural ruleset can be checked in as early as RIBA stages 1-2 because all the structural design elements are finalised at this stage. Comparatively, a ruleset concerned with medical equipment can only be checked after stage 5 and requires a LOD400 or more to have all the required information about the purchased and installed medical equipment in the BIM model.

3.2.3. Performing the automated check of the rules

Most of the studies in this stream took a specific code or regulation as a case study, for example, Liu et al. (2014) investigated an automated code checking for HVAC building code, while Zhang et al. (2013) applied it in the context of health and safety regulations. Martins and Monteiro (2013) developed an automated system in the context of the regulations of water distribution systems in buildings. These studies although have made a considerable effort to check a certain requirement but to date, there is very limited work done in creating a full model for automating healthcare facility codes using BIM models that are considering all the building regulations concerned with healthcare buildings.

3.3. CORENET

CORENET stands for (COnstruction and RealEstate Network), it is a government initiative by the Ministry of National Development in Singapore that started in 1995, and it is managed by the Building and Construction Authority. It represents the earliest code checking effort at a government level. The CORENET platform (http://www.corenet.gov.sg/) has three main parts: e-Submission that is used to follow up in building permits, e-Info guides different building stakeholders and e-PlanCheck that is concerned with automated code compliance. e-PlanCheck has two main modules the building plans module called IBP, and it has automated checks for rules concerning fire safety regulations, environment and sustainability regulations, and access control, building management systems and parking. The other module is concerned with checking building services, and it is called (IBS) (Eastman et al., 2009). This module includes rules for an automated check of electrical, plumbing, fire alarms, HVAC, water systems and gas pipes. CORENET is considered the most mature system for automated, rule-based check that is done so far.

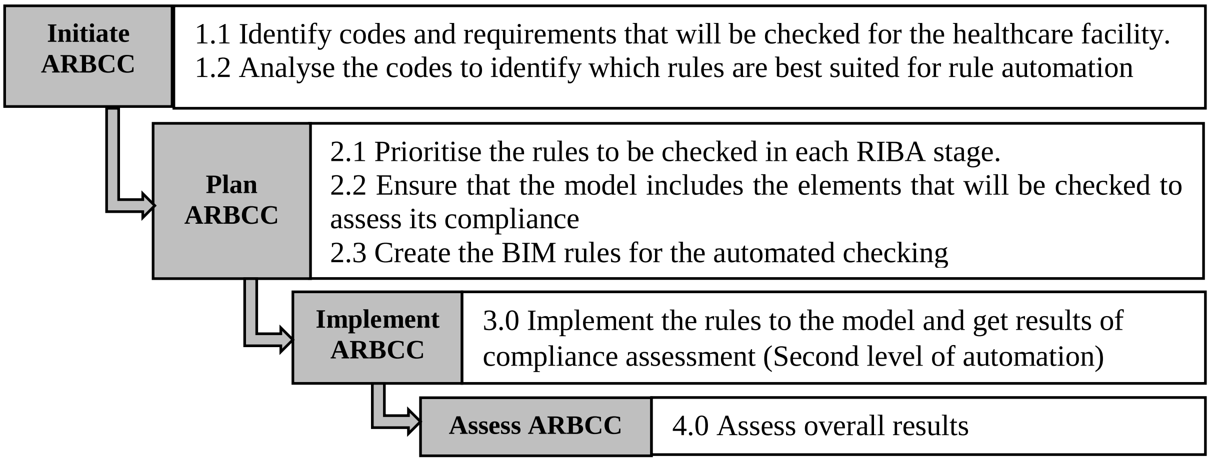
CORENET has a platform called FORNAX which is an object-based platform that uses IFC extensions and the definition of the rules that will be checked (Solihin, W, 2004). The most significant advantage of FORNAX platform is that it has the rules hardcoded in the platform, so that a programmer does not need to write a code to extract the IFC properties from the building code because FORNAX can understand the code written in natural language and translate it to the IFC property to check a specific building object. For the reporting of the check results, ePLanCheck has a website that can perform the check against the codes and report it in a PDF or HTML via the web browser, so a user does not need specific software to perform the test which is another advantage of the CORENET platform.

3.4. Solibri

Solibri is a commercial BIM model checking software that has several mechanisms and tools to check models. It includes a built-in set of rules based on building regulations and international standards such as fire codes and accessibility codes, the results of these checks can be presented visually or in a pdf or XML format file. An important feature that was added recently is that the platform enables users to edit the parametric value of built-in rules according to the standard used and even add additional rules based on the specific rules or requirements in the project at hand (Beach et al., 2013). One limitation of the platform is that the set of built-in rules are limited, and it covers only architecture design codes like accessibility, model elements, clash detection and ADA (American with Disability Act) compliance. However, to verify some of the complex client requirements in a healthcare facility, the rules must be created manually for each required check and uploaded to the software before the check can take place.

4. Proposed Automated Rule Based Code Checking model

Based on the review of literature and relevant work, and the problems identified in the process of capturing, assessing and automating requirements management, this section will introduce and analyse a new theoretical model that can be used in automating the process of requirement management in construction projects. The model namely Automated Rule-Based Code Compliance (ARBCC) consists of four main phases as shown in Fig 1:



1.1 Identify codes and requirements that will be checked for the healthcare facility.
1.2 Analyse the codes to identify which rules are best suited for rule automation

2.1 Prioritise the rules to be checked in each RIBA stage.
2.2 Ensure that the model includes the elements that will be checked to assess its compliance
2.3 Create the BIM rules for the automated checking

3.0 Implement the rules to the model and get results of compliance assessment (Second level of automation)

4.0 Assess overall results

Fig 1: Automated Role Based Code Check (ARBCC) Process Model

4.1. Stage 1: Initiate Automated Code Compliance

One of the common shortfalls identified in the literature for automated code compliance is the lack of clarity and consensus on what codes should be automated. Some studies focus on certain regulation, some studies focus on checking building guidance, and others focus on local and international standards, that's why the process of initiating the ARBCC platform is important because it will give a clear and definite description of what codes/requirements will be checked and why they are important. This stage will involve two stages: identifying the applicable codes and regulations for healthcare facilities (Oystein, et al., 2009) and analysing these rules to ensure their compliance check process can be automated using Building Information modelling BIM.

4.1.1. Collate the healthcare codes and requirements

A healthcare facility has to comply with the UK building regulations because these regulations are mandatory to all types of buildings in the UK. There are 16 building regulations in the UK (Gov.uk, n.d.) as detailed in Table 1.

Table 1: UK building regulations

No.	Regulation Code	Subject
1	Document A	Structure
2	Document B	Fire safety
3	Document C	Site preparation and resistance to contaminates and moisture
4	Document D	Toxic substances
5	Document E	Resistance to sound
6	Document F	Ventilation
7	Document G	Sanitation, hot water safety and water efficiency
8	Document H	Drainage and waste disposal
9	Document J	Combustion appliances and fuel storage systems
10	Document K	Protection from falling, collision and impact
11	Document L	Conservation of fuel and power
12	Document M	Access to and use of buildings
13	Document P	Electrical safety
14	Document Q	Security in dwellings
15	Document R	High speed electronic communications networks
16	Document 7	Material and workmanship

Compliance with these regulations is mandatory not just for healthcare facilities but also for any building in the UK, that's why these regulations will be a good start point to any automated code compliance check system in the UK because it will cover all the mandatory aspects related to building systems and services

Furthermore, for the healthcare-specific regulations and guidance, the National Health Services (NHS) in the UK has a set of design guidance for healthcare buildings that are called Health Building Notes (HBN) (Gov.uk, n.d.). These notes can be analysed as a base for requirement check automation using BIM. The regulations cover two types of regulations, building regulations that illustrates requirements related to the spaces of healthcare buildings such as lifts, stairways, bathrooms…etc. The other type of regulations is related to the design of specific healthcare functional space such as pharmacies, cardiac facilities, and critical care units. Table 2 provides a list of all the 29 HBN regulations.

Table 2: NHS's Health Building Notes

No.	Guidance Code	Subject
1	(HBN 00-01)	Designing health and community care buildings
2	(HBN 00-02)	Designing sanitary spaces like bathrooms
3	(HBN 00-03)	Designing generic clinical and clinical support spaces
4	(HBN 00-04)	Designing stairways, lifts and corridors in healthcare buildings
5	(HBN 00-07)	Resilience planning for NHS facilities
6	(HBN 00-08)	The efficient management of healthcare estates and facilities
7	(HBN 00-09)	Infection control in the built environment
8	(HBN 00-10)	Design for flooring, walls, ceilings, sanitary ware and windows
9	(HBN 01-01)	Designing and planning cardiac facilities
10	(HBN 02-01)	Cancer treatment facilities: planning and design
11	(HBN 03-01)	Adult mental health units: planning and design
12	(HBN 03-02)	Facilities for child and adolescent mental health services
13	(HBN 04-01)	Adult in-patient facilities: planning and design
14	(HBN 04-02)	Critical care units: planning and design
15	(HBN 6)	Designing facilities for diagnostic imaging
16	(HBN 07-01)	Satellite dialysis units: planning and design
17	(HBN 07-02)	Main renal unit: planning and design
18	(HBN 08-02)	Dementia-friendly health and social care environments
19	(HBN 09-02)	Maternity care facilities: planning and design
20	(HBN 09-03)	Neonatal units: planning and design
21	(HBN 10-02)	Facilities for day surgery units
22	(HBN 11-01)	Facilities for primary and community care services
23	(HBN 12)	Designing an out-patients department
24	(HBN 13)	Planning and design of sterile services departments
25	(HBN 14-01)	Designing pharmacy and radio pharmacy facilities
26	(HBN 15)	Planning and designing facilities for pathology services
27	(HBN 15-01)	Planning and designing accident and emergency departments
28	(HBN 23)	Designing hospital accommodation for children
29	(HBN 26)	Facilities for surgical procedures in acute general hospitals

The above two sets of regulations can form a good base for an automated platform of building codes and regulations for healthcare facilities in the UK. The next step in the framework is to analyse these codes and regulations and extract the rules that will form the base of the automated check.

4.1.2. Analyse the codes to identify which rules are best suited for rule automation

This phase of the initiation process is to analyse each code and guideline document to identify the rules that can be extracted from it and used for automated rule check using BIM. Rule extraction process in this stage can be manual, i.e. by reading the guidance and segmenting it into rules then transfer these rules into computer readable rule using the software. Or it can be automated extraction of rules using semantic web technology or machine learning algorithms that are used to extract rules from text. Every one of the two approaches to extracting the rules from the documents has pros and cons. In the case of manually written rules from regulatory documents, the main advantage of the process is that it will provide a clear, ready to use list of rules but obviously the process will be time-consuming, error-prone and will require extensive experience in many areas like design, building services, BIM and healthcare services (Sarel and Fernández-Solis, 2010). On the other hand, automating the process of rule extraction from documents is much faster, and less costly, but due to lack of maturity of the approaches and technologies used, the output may still need manual processing before being used for rule-based BIM checking.

Some of the requirements will not be possible to be automated for many reasons. This is because some requirements are qualitative and subjective and they are challenging to be transferred into a computer readable and checkable rule (Eastman et al., 2009). Also, some rules require human judgment and its compliance can't be checked using BIM models (Soliman Junior et al., 2019). Furthermore, some clauses will require a certain level of development that is very complicated to be achieved in the BIM model. Moreover, some rules require human judgement and can't be tested using without using human logic/reason to analyse. In these cases, a separate list of these requirements will be created and analysed to find ways to rewrite the requirements in a way that will be more suited with automation. The knowledge gained from this process of learning how to write requirements that are easier to be recognised and checked digitally will be invaluable for future codes and regulations writing.

4.2. Plan Automated Code Compliance

From the previous stage, a list of rules should be extracted from the codes and regulations documentation. However, these rules are not prioritised according to the stages of actual building design and construction (Kiviniemi et al., 2004). For example, in one document there will be rules about how space is organised in zones which is a piece of information that can be checked at RIBA stage 0-1. However, in the same document, there will be rules about the equipment and their specifications; this information is not available in the BIM model before stage 5 when the equipment is procured. To streamline the process of the compliance check, the different extracted rules must be classified according to the RIBA stages. This classification will answer the question "when" these rules must be automatically checked using the BIM model. Once the rules are prioritised, it can then be added in the software that will cross check it with the project BIM model (Zhang & El-Gohary, 2012). On the other hand, the lessons learned from the analysis of the text documents of the different regulations and the rules extracted from it can be used to inform future development of regulations, and specifically how to write the regulations in a machine-readable language that is easier to be automatically checked using computer software.

For the BIM model, this analysis can inform what level of development is required in the BIM model and for each asset in different RIBA stage (Alnaggar and Pitt, 2018) to allow for the automated check of the rules, and also the IFC attributes that needs to be included in the model. This can be achieved by analysing each rule extracted from the regulation documents, and assigning specific data that needs to be included in the model to allow the check of the specific rule. For example, a safety rule that requires the material of the floor in the corridors of a healthcare facility must be of a material that is not slippery. Analysis of this rule requires that the BIM model have information about the floor material in corridors areas. Similar to this example, the analysis of all the rules will provide a list of all LOD requirements in the BIM model. Finally, these requirements can be included as an appendix to a template asset information requirement (AIR) document that should be in place if the automated check is required. This AIR will make it clear for all stakeholders in the BIM supply chain about what information is required and why to allow for automated, rule-based check of the model.

4.3. Implement Automated Code Compliance

The output of the planning stage of ARBCC will have two parts:

- A list of all applicable rules that are extracted from the identified regulations for general buildings and healthcare-related codes and requirements.
- A List of the information requirements with its associated LOD that is required in the BIM model to enable the automated check of the regulation rules.

To implement this framework in a live project, it will require creating the extracted rules in a model compliance check software and applying the rules inside the software to check BIM model compliance.

As mentioned earlier, Solibri Model Checker (SMC) or similar software can be used to achieve this stage of the model. This automated implementation of compliance check will have several benefits. First, it will be much faster than checking compliance manually. It will require less effort from the designer, and it also does not require a high level of skills to implement (Pauwels et al., 2011). Furthermore, the quality of the check will be much higher than the manual check, and fewer check errors will be achieved.

4.4. Assess Automated Code Compliance

The assessment of the results out of the software will then provide insights about the design problems and non-compliance areas with the codes, regulations and requirements checked. Reporting these issues in all stages of building lifecycle will have significant advantages. First, it reduces rework and discovers design issues earlier in the project. It also decreases the cost and time associated with solving design issues because these issues are then solved in the model before it is implemented in the project.

5. Conclusion and future work

The process of requirements management for healthcare building projects is complex because it involves management of a large amount of information such as building codes, regulations and healthcare related guidelines. This information has to be managed across different stakeholders such as architects, design consultants, construction engineers, and facility managers. The process of manually checking these requirements across different phases of building lifecycle is costly, labour intensive, time-consuming, and error-prone. This paper proposed a theoretical model to automate compliance checking of healthcare building regulations namely ARBCC (Automated Rule-Based Compliance Checking). The model has four stages initiation, planning, implementation and assessment. The primary advantage of this model is that it conceptualises the automation of the process considering the three main parts of the code checking. First, identifying the relevant building codes and requirements and how to translate them into machine-readable rules. Second, specifying the Level of Development (LOD) for the BIM model to ensure the BIM model have the required information to allow for this checking. Third, using adequate rule-based checking software to check if the BIM model complies with the healthcare rules and regulations. The ARBCC model is based on the issues and previous work in different areas of automated code checking from the literature review. Further work is currently being undertaken to implement the model to a segment of healthcare documentation of NHS, to better assess its applicability and results. This work applies this process model in automating the code compliance checking using the Health Building Notes (HBN) by the UK NHS as a case study following design science research methodology to gauge its effectiveness and value in establishing the first digital platform for compliance checking of building codes and requirements in the UK construction industry. The ARBCC model is using a semi-automated approach because a specialist must manually check the regulations and translate them into rules to be checked by rule-based checking software. However, future research areas in compliance checking can use National Language Processing (NLP) and Machine-Learning algorithms to automatically extract the rules from the text documents of building code/regulations, and make the process fully automated.

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