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Designers' perspective on the use of automation to support regulatory compliance in healthcare building projects

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ABSTRACT

Automation has been long explored to improve regulatory compliance during building design. Despite substantial research efforts on developing means to enable this process, there has been limited success in practical implementations. Designers' inputs are often undervalued in such developments, leading to solutions that are not effectively incorporated into the design process. This issue is even more difficult in healthcare projects due to their complexity and convoluted regulatory frameworks. In this paper, we describe how designers perceive the use of automation to support regulatory compliance in healthcare projects, through the analysis of a series of semi-structured interviews. We found that regulatory documents have a large influence on design and their compliance often consists of an unformalised process in practice. Furthermore, we identified that subjectivity is perceived in requirements as needed due to the creativity involved in design, whereas automation can be understood as liberating in this context depending on how it is used. Improvement needs focussing on the revision of the regulatory framework as well as on software development have been highlighted by participants during the interviews, which led to the proposition of recommendations to help achieve their benefits in practice.

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Healthcare design; automation; regulatory requirements; compliance checking

Introduction

The healthcare building design process is complex and involves a large amount of information (Tzortzopoulos *et al*. 2006, Kasali and Nersessian 2015, Krystallis *et al*. 2015). Complex systems have different characteristics, including a large number of components and how they dynamically interact (Simon 1962, Cilliers 2005). Williams (2002) highlighted two key dimensions of complex systems: structural complexity and uncertainty. Whereas the first is associated with the large number of elements that interact and are interdependent, the second stems from a lack of clarity and agreement on project goals and methods (Williams 2002).

Considering healthcare design compliance, such complexity emerges from the characteristics of the product (i.e. healthcare facility), as well as from the building design process. They relate to the number of systems and components that interact in the built environment, leading to a plethora of requirements associated with building design, construction and operation (Braithwaite *et al*. 2015, Hicks *et al*. 2015) (structural complexity); as well as to the compromises and iteration between clients' and regulatory requirements, which can be incompatible and might change over time (Kiviniemi and Fischer 2004, Kollberg *et al*. 2006, Sengonzi *et al*. 2009, Baldauf *et al*. 2021) (uncertainty).

In the UK, the challenges arising from the use of the healthcare building design regulatory framework are noteworthy, as there is a confusion between statutory and guidance documents, developed under a fragmented and uncoordinated approach over the years (Hignett and Lu 2009, Mills *et al*. 2015). There are more than 100 documents describing healthcare design regulations or guidance documents, including for example: (a) design guidance provided by the Department of Health (DH); and (b) Building Regulations, which are mandatory for all buildings, provided by the Ministry of Housing, Communities & Local Government (Soliman-Junior *et al*. 2021).

In healthcare building design, regulatory requirements relate to functional and operational aspects of the built environment, associated with healthcare

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delivery needs and service outcomes (Tzortzopoulos *et al*. 2005). Information embedded in regulatory documents introduces different constraints to the building design process, intending to set a basic framework upon which design should be developed (Kamara *et al*. 2002, Jansson *et al*. 2013), as well as describing minimum requirements to ensure compliance (Toms 1988, Krystallis *et al*. 2015).

The use of automation can improve compliance processes by adopting a faster, more efficient, and accurate approach (Eastman *et al*. 2009). Automation, in this context, is related to the provision of computational support to ensure accurate compliance processes (Macit İlal and Günaydın 2017), as well as to support the coordination of information in building models (Kiviniemi 2005).

Existing literature suggests that a key challenge on using automation in compliance processes relates to how information is expressed in regulatory documents (Solihin and Eastman 2016). This issue is associated with the subjectivity embedded in the requirements' definition (Dimyadi and Amor 2013) as well as how automated approaches lack flexibility in adapting to the diversity of rules and contexts (Nawari 2019). Initiatives aiming to solve this problem reported in recent years have been undertaken mostly within the information technology domain (Beach *et al*. 2020) (e.g. Yurchyshyna and Zarli 2009, Zhang and El-Gohary 2015, Park *et al*. 2016), whereas designers needs and perceptions have often played a secondary role in such developments

This paper reports an analysis of semi-structured interviews, performed within the healthcare design context. It aims to investigate the use of automated approaches for healthcare regulatory compliance from a design standpoint, as well as highlights improvement needs identified in practice. The premise of the paper is that regulatory compliance manifests through design, hence the scope of this investigation is focussed on the design process in relation to automation and compliance.

This study was driven by the following questions, considering the UK healthcare building design context:

- How the use of automation to support regulatory compliance is perceived in healthcare building design practice?
- How statutory and guidance documents impact the practical adoption of automated compliance checking?

The paper is structured as follows: after the introduction, the research background is presented aiming to provide a basic theoretical framework upon which the interview protocol was created. Indirect sources of evidence have also informed this process and they are further described in the research design section. Findings are presented based on the analysis of interviews and according to the main themes that originated after the coding process. This is followed by a discussion section that aims to analyse research findings by connecting them to the theoretical framework associated with the paper, highlighting key contributions to theory, practice, and policy. After the discussion section, our final remarks are presented according to the main topics explored by participants during the interviews and provide an outlook for future research. The above structure is illustrated in Figure 1.

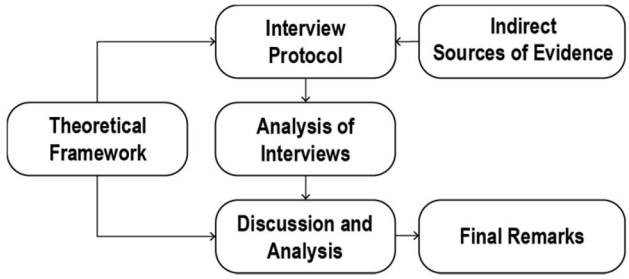

Figure 1. Structure of the paper and connection with the theoretical framework.

The healthcare design process

The healthcare building design process involves requirements from several stakeholders, such as end-users (e.g. doctors, nurses, administrative, cleaning and maintenance staff, patients and their family members) (Ransolin *et al*. 2020), as well as design, coordination and construction teams, local authorities, consultants etc. During design, stakeholders express and conceptualise requirements differently and designers consider them as "means through which design could be developed" (Tzortzopoulos *et al*. 2006, p. 678).

In this context, Von der Tann *et al*. (2018) suggest that designers either abide by the rules expressed in regulatory documents, adopting a prescriptive approach to design; or use regulatory information as a foundation upon which their own creative process is built. The above reasoning indicates that codes, guidance, and other statutory documents which are part of the regulatory framework have a significant impact on design not only in terms of defining minimum standards to ensure compliance but also as triggers to design decision-making, creativity, and innovation.

Creativity is intrinsic to every design project and is influenced by the problem being resolved, the design

situation, resources available and the designers' own goals (Dorst and Cross 2001). Creativity is also described by existing literature as influencing design reviews and compliance checking (Nawari 2012b). Verifying the compliance of designs to guidelines, regulations and other statutory requirements is an important step in the design process (Dimyadi and Amor 2013; Nawari 2013), through which inconsistencies between design and requirements can be identified (Parsanezhad *et al.* 2016). This process also determines if requirements are satisfied and whether design performs as specified (Christensen and Ball 2016). In the UK, healthcare projects are also assessed according to the design quality indicator (DQI).

The DQI consists of an important evaluation process based on a set of quality criteria (Thomson *et al.* 2013). This approach is derived from the Vitruvian pursuit of design excellence by building quality, function and impact (O'Keeffe *et al.* 2015), and originated from assessment instruments named "Achieving Excellence Design Evaluation Tool" (AEDET) and "A Staff and Patient Environment Calibration Toolkit" (ASPECT), as part of a Design Quality policy (DQP) (O'Keeffe *et al.* 2015). The DQI process is mandatory at key design stages, aiming to assess design proposals by a panel of stakeholder representatives (O'Keeffe *et al.* 2012, Thomson *et al.* 2013, Anåker *et al.* 2017).

Existing literature is critical on the effectiveness of this process, as there are important risks associated with its reductionist approach, as well as to challenges related to the complex social phenomena which are part of healthcare design evaluation (O'Keeffe *et al.* 2012, 2015, Thomson *et al.* 2013). Considering the context of this paper, the above means that despite the importance usually attributed to the DQI process, it generally consists of a generic approach, not exactly focussed on design compliance. This might lead to a process that overlooks building compliance to regulatory requirements and its impacts on design quality and service delivery.

Information on requirements and the automated compliance process

Ulrich and Eppinger (2016) suggest that subjective sentences are generally used to express users' needs in the design process. Subjectivity is also observed in regulatory requirements, as they are often vague, ambiguous and abstract (Fenves *et al.* 1995, Nawari 2012a, Dimyadi and Amor 2013). Therefore, interpreting and translating requirements is needed to develop a design solution (Darlington and Culley 2004), as well as to assess and check design against requirements (Solihin and Eastman 2016), whereas creativity is intrinsic to both processes.

Despite acknowledging that human involvement is needed to interpret and translate design requirements (Amor and Dimyadi 2021), when it comes to compliance activities it is often mentioned as a source of uncertainty, leading to prone-to-error and biased outcomes (Eastman *et al.* 2009, Ghannad *et al.* 2019). This reasoning suggests a paradox concerning the human involvement in this process, implying that requirements' subjectivity could be simply eliminated by using automated compliance approaches, without impacting on requirements' definition and design creativity.

This shortcoming generally understands compliance as a separate process from design development (Hjelseth 2016). Additionally, it does not consider the iterative design character (Dorst and Cross 2001, Christensen and Ball 2016) as well as its intrinsically creative and subjective nature (Crilly 2019), which is also reflected in current regulatory frameworks (Nawari 2019). Such perspective is also limited as automated approaches will hardly be independent of human designers' inputs due to the indeterminacy of requirements involved in design (Fenves *et al.* 1995, Nawari 2019, Amor and Dimyadi 2021).

Despite the important move reported in existing research towards automated compliance over the last decades (e.g. Melzner *et al.* 2013, Lee *et al.* 2014, Zhang and El-Gohary 2015, Park *et al.* 2016, Macit İlal and Günaydın 2017, Nawari 2019, Solihin *et al.* 2020), practical outcomes are still very limited. Nawari (2019) identified three main types of platforms used for automated compliance checking: (i) a software application integrated into a specific design tool, such as a plug-in; (b) a stand-alone software application disconnected from modelling tools; and (c) a web-based application which can verify designs from different sources. Nevertheless, the referred author highlights several constraints from these approaches in practice mostly due to hard-coded rule-based representations, which cannot represent the diversity of existing requirements and often lead to a series of issues related to cost, maintenance and flexibility in these systems (Nawari 2019).

Additionally, only one stand-alone commercial tool that supports automated rule checking by using open standards is acknowledged by the literature i.e. Solibri Model Checker (SMC) (Solihin *et al.* 2020). However, even within SMC automated compliance is restricted to some specific types of requirements (Mendonça *et al.* 2020) due to pre-defined rulesets with limited

flexibility (Melzner *et al.* 2013, Preidel and Borrmann 2016, Schwabe *et al.* 2019).

From a process perspective, there are different understandings reported by the literature of how regulatory compliance is considered in the design. Most developments focus on compliance as a checking activity that is detached from design development. It is usually performed at predefined or agreed times with emphasis on quality control and handover (Eastman *et al.* 2009, Hjelseth 2016), or on the definition of liabilities due to evolving design changes (Shipton *et al.* 2014). Compliance can also be understood as embedded into design development, as a continuous and unified process towards quality assurance (Dimyadi *et al.* 2016, Hjelseth 2016, Amor and Dimyadi 2021).

Research problem

The use of automated approaches to support regulatory compliance in healthcare projects is the focus of this paper. In fact, there are several potential benefits reported by existing research emerging from its application, and they become especially relevant while considering the characteristics of healthcare projects, such as the large number of requirements and stakeholders, as well as the complexity arising from the dynamic systems and elements that interact in this type of building. There has been extensive research dedicated to automated compliance for many years, and developments were mostly conceived from an information technology background. Despite providing some clarity towards the resolution of such problem and advancements in the research field, practical outcomes are limited to some specific types of requirements and applications, leading to a series of challenges during design.

The poor consideration of how designers consult and refer to regulatory documents during healthcare design projects, as well as how design is assessed against regulatory requirements from a process perspective, make the benefits from automated compliance difficult to achieve in practice. Indeed, existing literature has shed some light on how designers use guidance documents such as Health Building Notes (HBNs), and their influence in the healthcare design process (Hignett and Lu 2009, Mills *et al.* 2015), as well as how healthcare design quality is evaluated in the UK (Thomson *et al.* 2013, O'Keeffe *et al.* 2015, Anåker *et al.* 2017). Nevertheless, there is still a gap in identifying and connecting designers' needs and inputs to automated regulatory compliance developments in this context.

Research design

This paper is part of a research project that adopts the Design Science Research (DSR) methodological approach. DSR is focussed on the development of artefacts to solve real-world problems while providing a prescriptive scientific contribution (Dresch *et al.* 2014). It has been recently used as the underlying methodological approach of many research projects within the healthcare building design domain (e.g. Ransolin *et al.* 2020, Baldauf *et al.* 2021, Caixeta and Fabricio 2021).

A typical DSR research project is divided into three stages (Holmström *et al.* 2009): (i) understanding the problem; (ii) development of the artefacts; and (iii) analysis and reflection. This paper is focussed on the analysis of one source of empirical evidence that supported the larger research project during the first and second stages, namely semi-structured interviews. Other sources of evidence that were part of this research project, as reported in Soliman-Junior *et al.* (2021), and indirectly informed this paper relate to: (i) in-depth analysis of regulatory and design documents; (ii) design assessment reports; and (iii) participation in healthcare design project meetings. In this context, the main purpose of the analysis here presented is to clarify issues around the automated compliance process from a design perspective through the interviews.

Despite the prescriptive character which is typical of DSR projects, the analysis presented in this paper is rather descriptive. Because of the practical relevance of the research questions explored in the paper, the perceptions and knowledge from designers and other practitioners related to healthcare projects are essential. In this context, such descriptive analysis enables an in-depth exploration of the problem from a practical perspective, which will further support the development of the research artefact (and its associated prescription). This approach is not new and can greatly complement DSR projects, as reported by Botes *et al.* (2014).

Therefore, a qualitative approach has been adopted to this particular segment of the research, to support exploring and analysing specific topics (Creswell and Poth 2018). This type of approach has been used across many studies within the architectural and engineering design domain (e.g. Kagioglou *et al.* 1998, Crilly 2015, Zou *et al.* 2019, Lee *et al.* 2020), also with

Table 1. Participants' profile and summary of interviews.

Participant	Domain	Job title	Interview	Type	References
1	Architectural Practice	Senior Architect	1	Face-to-face/Individual	36
2	Architectural Practice	Regional Director/Senior Architect	2	Face-to-face/Individual	34
3	Architectural Practice	Healthcare Lead/Senior Architect	3	Face-to-face/Group	44
4	Architectural Practice	Studio Director	3	Face-to-face/Group	
5	Healthcare Estates	Director	4	Face-to-face/Individual	13
6	Higher Education	Professor/focus on Design	5	Face-to-face/Individual	38
7	Higher Education	Professor/focus on Digital Design and Requirements Management	6	Questionnaire	13
8	Higher Education	Professor/focus on Automation	7	Face-to-face/Individual	28
9	Architectural Practice	Studio Director	8	Virtual/Individual	39
10	Architectural Practice	Studio Director	9	Virtual/Individual	52
11	Architectural Practice	Associate Architect	10	Virtual/Individual	40

a specific focus on the British healthcare building design context (Hignett and Lu 2009, Price and Lu 2013, Krystallis *et al*. 2015, Mills *et al*. 2015).

Population of experts

A group of 11 participants with relevant practical experience in healthcare building design has been selected to collaborate in this research, forming a population of experts. This process received ethical approval from the University of Huddersfield and followed its guidelines. Participants who took part in the interviews kindly agreed to contribute to this study, and they are experts in the areas of healthcare building design, higher education, and healthcare estates. Based on the five-stage model of skill acquisition proposed by Dreyfus (2004), experts are individuals who have extensive experience and skills in their field and rely on personal intuition to achieve successful outcomes. In this context, they are capable of swiftly responding to an evolving situation and making substantial contributions to their domain (Benner 2004). The participants' profiles are described in detail as follows.

Most of the participants are architects with relevant experience in the design of healthcare projects. Participant 1 has over 20 years of experience in the development of architectural projects, focussing both on healthcare and environmental design. Participant 2 is a senior architect and regional company director, specialised in primary care and mental health design. Participants 3 and 4 are from the same company, which is focussed on healthcare projects. While the first is the healthcare company lead, having wide experience in primary and acute care as well as in mental health projects, the latter is a studio director with an architectural technology background, specialised in the design of complex healthcare projects. Participants 9, 10 and 11 are from another architectural company with a strong focus on healthcare. Participant 9 is a studio director with over twenty years of experience on local and international healthcare projects. Participant 10 is an experienced architect with a background in digital technology and automation; and participant 11 is an associate architect with experience in healthcare space planning and project feasibility.

Representatives from the higher education sector also participated in this research. They have been carefully selected because of their practice-based experience, either due to research initiatives, but also because of their internationally acknowledged developments in collaboration with design practice. Participant 6 is a professor and director of a design research centre with multiple healthcare-related projects. Participant 7 is a former professor of digital architectural design with a strong background in architectural design practice. Participant 8 is a professor with a practical background in construction and research on digital technology, automation and robotics within the architecture and engineering domains. In addition, participant 4 represents an important UK healthcare organisation and has a strong background in innovation and technology development in this context.

A summary of the participants involved in the research is presented in Table 1. It includes their domain, job title, as well as how the interviews were conducted and the number of references that originated from each of them (according to third-level codes).

Interview protocol

All the interviews adhered to a semi-structured interview protocol, and the main sample questions are summarised in Table 2. Semi-structured interviews are useful in situations that require a flexible approach for data collection, in which it might be necessary to understand the specific constructs that participants use as a basis for their opinions and beliefs on a certain situation (Easterby-Smith *et al.* 2015).

The questions were designed around two key areas: (i) regulatory framework: statutory and guidance

Table 2. Summary of semi-structured interview protocol.

Purpose	Example questions
Regulatory framework: statutory and guidance documents	
Influence of regulatory framework in design	In which ways the regulations (e.g. Building Regulations) and other design guidance (e.g. HBNs/HTMs) influence the design process? To what extent?
Development of regulatory documents	Do you think that the way these documents were developed impact achieving design compliance?
Use of documents in practice	Do you think the way design guidance (e.g. HBNs/HTMs) are presented at the moment is appropriate, considering the healthcare design process and the way documents are consulted and referred to?
Revision of documents	If NHS guidance documents were to be reviewed, what would be the key aspects that need improving? Why?
Automation for compliance in the healthcare design process	
Positioning	Do you think that an automated-based tool/system for compliance would be beneficial to the design process?
Design operations	Which specific design tasks do you think could be impacted the most (positively)?
Impacts of automation	Do you think that automation could be harmful in any way to the design process? If so, in which ways and why?
Relationship to subjectivity	Do you think that automation in the design process, specifically for compliance, goes against keeping the subjectivity associated with the design? If so, why?
Design stages	If so, what are the key stages you see this as fundamental and why?
Benefits of automation	Who could potentially benefit from the use of a degree of automation to support compliance in the healthcare design process (e.g. architects, other members from the design team, client, NHS, etc.)?
Future of automated compliance (design)	How do you see the future of automated approaches to compliance being incorporated into your design process?
Future of automated compliance (software)	In an ideal scenario, what type of automated tools/systems you would like to have to help you ensure design compliance?

documents and (ii) automation for compliance in healthcare design. This protocol was developed in response to issues identified in the literature and highlighted above, as well as to support an understanding of how automation can help to ensure compliance and to streamline the healthcare building design process. The semi-structured interview protocol has been reviewed and refined multiple times before its use for data collection through internal pilot applications with the research team, as recommended by Saldana (2011).

The same interview protocol has been used with all the participants. Because of the semi-structured approach adopted for data collection, follow-up questions were asked either when further clarification was needed or to incite supplementary elaboration on specific emerging topics mentioned by the participants while answering the main questions. Examples of these follow-up questions are:

- *"You mentioned you used Dynamo to support compliance, could you explain this in more detail?"*
- *"You mentioned this research field should move forward, so what are the existing gaps?"*

Data collection

All interviews were undertaken individually and by the same researcher, with exception of participant 7 (Interview 6), which preferred answering a written questionnaire[1]; and participants 3 and 4, which preferred to have a group interview instead of individual ones. When interviews happened face-to-face (participants 1–6 and 8), audio was recorded with an external device (e.g. voice recorder). In virtual interviews (participants 9–11), Microsoft Teams has been the platform used for video calls, with recordings being safely stored on a restricted cloud-based system. In all events, the protocol has been explained to participants before data collection, with key definitions and terms being presented and discussed beforehand, aiming to ensure consistency and avoid misunderstandings.

The entire data collection process was approved by the University of Huddersfield ethical committee. For ethical purposes, all interview files (e.g. recording files and transcriptions) were anonymised, and the participants' names have been replaced by numbers. The interviews' duration ranged from approximately 35 minutes to 70 minutes. Immediately after each interview, the main aspects, insights, and interviewers' notes were incorporated into a database, to systematically create a repository of information to support subsequent data analysis.

Data analysis

Data analysis included a detailed and systematic examination of the transcriptions to identify constructs and their relationships. This process is known as coding (Saldana 2009). The adopted coding approach followed an inductive process (Creswell and Poth 2018).

Table 3. E xample of the coding process (first stage).

Interview excerpt	Codes (first stage)
So, for me [1]automation works whereby the [2]boring stuff is done by the computer and the [3]creative stuff is done by [4]us.	[1]AUTOMATION
Relationship between codes	[2]REPETITIVE ACTIVITIES
[1]AUTOMATION – [2]REPETITIVE ACTIVITIES	[3]CREATIVITY
[3]CREATIVITY – [4]HUMAN REASONING	[4]HUMAN REASONING

Interview transcripts were analysed in Microsoft Excel for early definitions of constructs and relationships, as well as by using QSR Nvivo 20, a qualitative data coding and analysis software for in-depth coding.

Inductive coding consists of an iterative process in which data from interviews is organised into themes, whereas codes naturally emerge from their contents, meaning that more specific and context-based information is gradually organised into more abstract units (Creswell and Poth 2018). This process followed the "descriptive coding" approach (Saldana 2009, Miles *et al.* 2014), by summarising in a word or short phrase the fundamental topic of interviews' excerpts (Miles *et al.* 2014). This iterative process ensures continuous refinement to the ongoing data analysis.

First coding stage

The first coding stage involved a descriptive analysis of transcripts, based on the identification of constructs emerging from the participants' responses and key relationships between them. This process was undertaken in Microsoft Excel and used a qualitative approach to identify key constructs in excerpts, highlighting common relationships. This initial coding process is illustrated in (Table 3), by a sample coded interview excerpt.

Saldana (2009) suggests that descriptive coding leads to a primary but fundamental categorised data inventory, which can be further analysed. The process described above was essential to better contextualise findings and triggered a second coding stage, through the definition of themes and robust codes used for an in-depth analysis of the interviews. During the first coding stage, 129 codes were identified, representing key constructs emerging from the interviews. From these, 176 unique chains of codes (relationships) have been identified, which are represented in Figure 2.

For this analysis, preliminary codes have been mapped and structured as chains. They were arranged starting from the regulatory framework and structured according to their relevance to (i) healthcare design and (ii) automated compliance; the (iii) consequence of identified relationships; and (iv) their outcome, at a higher level of abstraction. The diagram in Figure 2 shows the most common connections between constructs. Relationships that occurred multiple times in the interviews have been proportionally represented in Figure 2 by wider lines. They indicate relevant topics mentioned during the interviews, which were used as inputs to the second coding stage. Considering the coded excerpt above (Table 3), a relationship between automation (1) and repetitive activities (2) is observed right at the centre of Figure 2, whereas the link between creativity (3) and human reasoning (4) is indicated at the top of this diagram. The same process has been undertaken for all preliminary codes and is illustrated in the diagram below.

Second coding stage

During the second coding stage, preliminary codes and relationships from the first stage have been analysed (Figure 2) and refined to a more robust set of codes (70 codes – third level) with support of QSR Nvivo 20. They have been organised as indicated in Table 4, which also includes the number of references from interviews of each second-level code.

During the second coding stage, fragments from the interviews were associated with codes adopting a non-exclusive approach, meaning that one segment of the transcript could be assigned to more than one code. Third level codes are discussed in the following section.

Findings

In this section, we describe key findings that emerged from the analysis of interviews. They include the participants' perceptions of the healthcare building design context in relation to automated compliance, the identified patterns regarding the characteristics and limitations of such systems, as well as challenges emerging from the existing regulatory framework.

How is the healthcare design context described by the participants in relation to automated compliance?

The healthcare building design context in the UK is highly influenced by the existing regulatory framework. This has been identified by participants according to

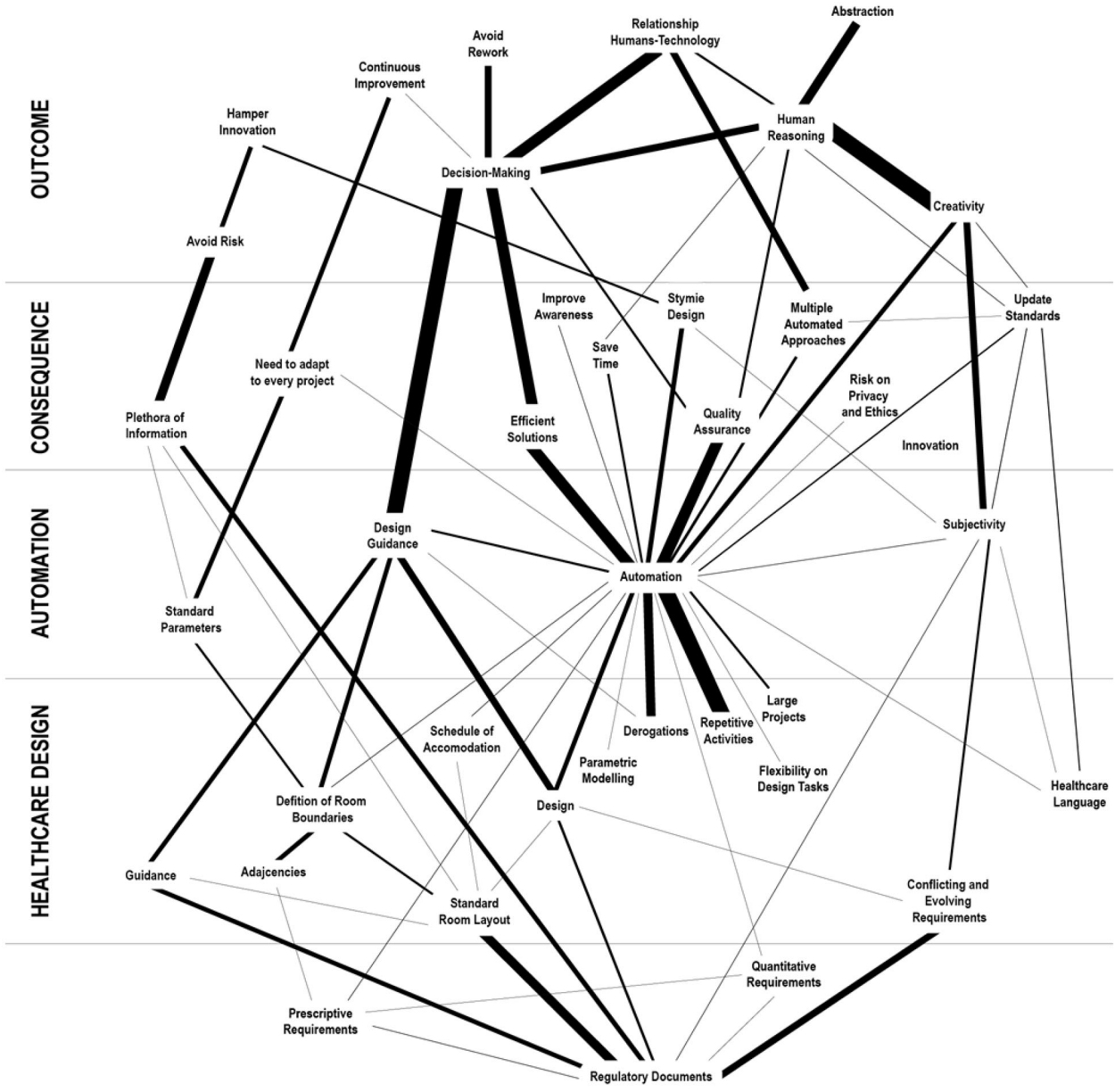

Figure 2. Coding: first stage – key relationship diagram.

Table 4. Coding: second stage.

First level	Second level	# Codes (third level)	References
Healthcare Building Design	Healthcare building design process	11	56
Healthcare Building Design	Healthcare design characteristics	6	47
Regulatory Framework	Characteristics of the Regulatory Framework that enable automated compliance	3	12
Regulatory Framework	Issues with existing documents and requirements	14	58
Regulatory Framework	Requirements' subjectivity	6	12
Automated compliance	Characteristics of automated compliance	10	45
Automated compliance	Benefits of automated compliance	7	28
Automated compliance	Gaps on existing approaches for automated compliance	10	54
Automated compliance	Understandings of automated compliance in design	3	25

factors such as: (i) incorporating and checking requirements from documents in the design solution (participants 1, 2, 6, 7, 10, 11); (ii) supporting abstract design decision making (participants 6 and 10); (iii) being key drivers in bridging liabilities and risks during design (participants 4, 5, 11); and (iv) by supporting design

quality evaluation through the DQI (Design Quality Indicator) process (participants 1 and 9).

Different topics were identified by participants as related to different healthcare design stages. Early design stages are particularly influenced by HBNs (participants 1, 2, 12) and relate to resolving adjacencies and space layouts (participants 1, 2, 3, 9, 11). During this stage, the schedule of accommodation was mentioned as a key document (participants 1, 2, 3, 11) reflecting an important link between the architectural design process and the healthcare clinical plan, which is understood as a key design driver (participant 2). During early design, room layouts should be generated quickly, as they aid the basic definition and visualisation of floorplans (participant 1), as well as support mediation and the resolution of potentially conflicting requirements (participant 2).

In this context, the use of standard room layouts has been observed as a common practice that could facilitate automated compliance (participants 1, 2, 3, 4, 9, 10 and 11). This topic has also been discussed by existing literature (e.g. Kasali and Nersessian 2015, Krystallis *et al.* 2015) in the US and UK, respectively. Furthermore, creativity has been mentioned as the main driver in healthcare building design (participants 2, 3, 6, 8, 10) and its relationship with requirements' subjectivity will be further discussed in the paper.

As design moves from the concept to detailed and technical stages, Health Technical Memoranda (HTMs) and building regulations become more important, in contrast to HBNs (participants 1, 2, 4, 6 and 11). Participant 6 mentioned that at this stage, specialist consultants generally start to get more involved in the design (e.g. fire safety, ventilation, M&E), leading to a more intense prescriptive approach in terms of referring to documents, checking compliance and analysing derogations (participant 2, 3, 4, and 6). During the healthcare design process, collecting, translating, and tracking requirements are fundamental activities associated with requirements management (participants 6 and 11), whereas the complexity arising from this process is remarkable (participant 11).

Participants also described characteristics that influence the healthcare design process, as well as the adoption of automated approaches to support compliance. The iterative character of the design due to evolving requirements has been highlighted by participants 1, 7, and 9. Iterative processes have been also connected to compliance and design approvals. Participant 8 described the above as leading to constant redesign and rework while describing how different healthcare projects are often assessed.

Derogations are indicated as a key instrument in the healthcare design compliance process in the UK (participants 1, 2, 3, 4, 5, 9, 10). Their use in practice is observed as more than just a liability instrument used to clarify, justify and sign-off non-compliances. According to participant 9, "*we're on an environment of design by derogation rather than design by compliance*", suggesting that the design culture might be changing, and derogations are one of the main drivers in this process.

What are the characteristics of the regulatory framework that enable automated compliance?

In the UK healthcare design context, Health Building Notes (HBNs) and Health Technical Memoranda (HTMs) are understood as key best practice design standards. They are developed and managed by the Department of Health (DH) and provide "essential information on how to comply with the statutory and policy framework around the assurance of estates and facilities" (Department of Health and Social Care 2014, p. 2). The guidance purpose of these documents has also been observed in practice (participants 1, 3, 4, 7, 10 and 11), highlighting an important link between them with the creative aspect of the design process (participant 10).

Within this regulatory environment, some characteristics identified by the participants facilitate the use of information from documents in automated compliance activities. They are mostly related to (i) prescriptive requirements and (ii) quantifiable requirements. Participant 9 mentioned that prescriptive requirements were addressed in their company through in-house compliance plug-ins developed in Dynamo, a visual programming language (VPL) application. A similar reasoning was used by participant 11, while discussing that prescriptive requirements could already be embedded as parameters into objects used in modelling tools such as Autodesk Revit. Quantitative requirements have been mentioned by participants 6, 8 and 11, while creating a direct link to automated compliance. Participant 11 includes another element to what can be "*quantifiable and algorithmically solvable*", related to spatial geometric data, describing how spatial objects, walls, floors, and ceilings can be represented by grids to enable automated checking of clearances, as well as inclusion and exclusion criteria.

What issues are observed in design practice with the existing regulatory framework?

Regulatory documents have an important role to support decision-making in healthcare design, but there

are multiple challenges related to their use in practice. Different issues with the existing regulatory framework have been mentioned during the interviews, and they tend to be amplified considering their use in automated compliance systems.

In the UK, there is great confusion between guidance and statutory documents (participant 6), and what is their role in the compliance process (participant 10). This is because requirements are not clearly described either as mandatory or guidance from best practice, leading to a confusing compliance environment in which risks and liabilities are not clearly defined (participant 10). Additionally, this unclear setting increases uncertainty for designers, leading to compromises on basic design principles and, ultimately, constraining creativity and innovation (participant 6).

In fact, the link between regulatory requirements, creativity and innovation is defined by participants 5, 8 and 11, with a strong focus on different inclinations towards risks assumed by designers and regulators. Additionally, risks during the design process have also been connected to derogations, being influenced by the clients and the scope of each project (participants 1 and 10).

Issues associated with the convoluted regulatory framework as described above are amplified by the complexity arising from the plethora of documents in the UK (participants 3, 4, 6, 10, 11). Documents such as HBNs, HTMs and Building Regulations are mentioned as outdated and unfit for purpose, considering their use in the daily design practice, as well as specifically focussed on automated compliance (participants 6 and 10). Such documents affect automated compliance because of incompatibilities arising (i) from their creation or revision, as well as (ii) how information has been included in their requirements (participants 9 and 11). Furthermore, documents have been developed and updated in a piecemeal way over the years, while many have been superseded, leaving gaps on the existing regulatory framework, and referring to obsolete documents (participant 11).

In fact, the existence of conflicting requirements in the regulatory framework as mentioned by participant 11 is understood as a main challenge (participants 2, 7 and 8), as well as the fact that "*regulations have been written for humans, not for computer software, and in most cases, they are fuzzy and difficult to interpret and check automatically*" (participant 7). This is further aggravated because information from the documents can be very complex and abstract (participant 2), hence being difficult to apply in automated compliance systems.

The subjectivity embedded in requirements has been identified as a key challenge in relation to automated compliance (participants 3, 4, 6, 8, 9, 10 and 11). According to the participants, subjectivity is an intrinsic part of the healthcare building design process and cannot be simply eliminated (participant 9).

Subjectivity can also be introduced in the compliance process because of the interpretation that is needed to "*read the documents*" (participant 11). Despite the emphasis on the difficulties introduced by subjective requirements, they are described as needed in the regulatory framework to "*protect*" the creative aspects of design (participants 6 and 11), being also fundamental triggers to innovation in healthcare (participants 5, 9 and 10). Furthermore, participant 9 mentioned that subjectivity needs to be managed and its benefits enhanced, even within a digital environment. The same participant understands that subjectivity can potentially be automated by using a large dataset to support decision-making. In this context, the subjectivity embedded into requirements should be seen as an opportunity to expand current digital agendas, especially in the healthcare sector (participant 9).

The challenges discussed in this section have led participants to reason about the need to update documents from the UK regulatory framework. Key improvements that would need to be considered in future revisions to enable better and further use of automated approaches to compliance during design are presented in the discussion section.

How automated compliance is perceived in the healthcare building design practice?

The use of automated compliance approaches has been suggested to be more beneficial to larger healthcare projects (e.g. hospitals and other complex buildings), in contrast to smaller facilities such as primary health centres (participants 1 and 2). The use of automation is understood in practice as related to "*specific, well-defined routine sub-tasks*" (participant 7).

This use has been summarised by the participants as focussed on repetitive and elementary design activities (participants 2, 3, 4, 7, 9, 10, 11). While participant 2 suggests that automated compliance approaches can work in practice as a *"shortcut"* in the skills development context, facilitating the work of novice designers; participant 4 highlights that it should be used for the *"boring"* tasks, such as checking door schedules and fire properties, while human designers should focus on value-added activities. The latter perspective is also evidenced by participant 9, suggesting

that automated compliance should be used for checking dimensions such as columns and corridor widths. Furthermore, the use of parametric modelling[2] has been highlighted as an enabler of automated compliance, which can support not only compliance checking but also improved design decision-making through built-in compliance (participants 1 and 10).

In this context, the use of different automated approaches for regulatory compliance has been acknowledged as fundamental within the digital design context (participants 3, 4, 6, 7, 8, 10, 11). The above examples suggest that different designers react differently to automation, which has also been explicitly confirmed by participant 8. These different understandings of automated compliance in design will be further described in the paper.

The use of automated compliance approaches should lead to a series of benefits to all stakeholders (participants 5, 6, 9, 10, 11). Flagging non-compliances in design (participants 1, 2, 4, 11) and improving stakeholders' awareness (participants 5 and 9) have been mentioned as key benefits arising from their application.

From a process perspective, time savings relate to improving design coordination and compliance checking (participant 10), as well as freeing up designers to work on other activities (participant 9). In this context, the use of automation enables multiple checking points during design to avoid rework (participants 3, 6, 8). Participant 3 has also highlighted the need for transparency in the automated checking process, improving the confidence of all stakeholders, especially the NHS.

What are the gaps of existing approaches for automated compliance from a design perspective?

As already discussed, the way information is embedded in regulatory documents is critical to enable automated compliance. While discussing its specific role, participants highlighted other important gaps, indicating that challenges faced in practice also link back to different aspects of the healthcare design process.

Participant 7 drew upon his extensive experience, indicating that "*if the automated solution does not take the complexity of the design into account and the users cannot specify the importance of the different requirements correctly, the results can be very bad – especially if people trust that the computer is always right*". In this context, the use of automation was pointed as a major constraint to the creative aspects involved in healthcare building design (participants 2, 3, 4, 6, 7, and 10). Participant 10 further suggests that a more balanced approach between creativity and compliance is needed: *"you have to kick the ball and get it in this zone, rather than kick the ball and hit this spot"*.

In this context, human knowledge and inputs are described not only as needed but fundamental to the success of automated compliance approaches (participants 3, 4, 8, 9, 10, 11). This is because participants recognise there is no *"one size fits all approach"* (participant 11) in healthcare design, whereas all abstract and intangible design aspects rely on human involvement (participant 6). Specific issues associated with automated compliance in healthcare design also refer to (i) the lack of a digital way to capture and check requirements (participant 6); and the need for a healthcare language across sectors (participant 9).

Multiple topics emerged when participants were asked about future needs of automated compliance both from a design perspective, but also by exploring and identifying specific topics to software development. They will be presented in the discussion section.

What are the different understandings of automated compliance in design practice?

Participants evidenced different understandings on the practical application of automated compliance: (i) to substitute human designers; (ii) to provide guidance to designers towards better decision-making; and (iii) to enhance the capacity of designers while providing compliant solutions that might not be traditionally achieved by them.

Automation as a **substitute** (participants 2, 3, 4, 8, 10, 11) relates to repetitive and non-value adding activities. The focus is on automating specific, repetitive, and quantitative compliance tasks that are developed faster and more accurately by computer systems. A common understanding from participants is that automation as a substitute would free designers to have more time to dedicate to complex and creative design activities (participants 2, 3, 4, 8, 9, 10).

The **guidance** understanding is associated with participants acknowledging that regulatory requirements might be subjective, relying on designers' interpretation and creativity (participants 1, 3, 4, 6, 9, 10). Automation can aid designers in their decision making, by providing the necessary information when it becomes needed. Key benefits of this approach, according to the participants, are related to avoiding design rework and promoting continuous improvement and assistance.

The use of automated compliance was also understood as an **enhancer** to human designers' skills (participants 5, 8, 9, 10, 11). This is due to the possibility of exploring and simulating a large set of potential design options with relative ease, expanding the solution space by incorporating inputs from automated approaches, such as by using generative design[3] and artificial intelligence (participant 10).

Both guidance and enhancement understandings relate to improving decision-making during design in terms of compliance. While the first provides a "shortcut" to access information which designers would be able to reach by themselves with dedicated time and efforts, the second relates to expanding the solution space in such a way that designers would probably not be able to achieve the same outcome on their own.

Discussion and analysis of findings

This section will summarise and analyse the main findings from the interviews after the coding process. It is focussed on connecting outcomes from the analysis of interviews to the theoretical framework associated with the paper. Therefore, it highlights the main contributions of this work in relation to theory, practice and policy.

Contributions to theory & practice

Healthcare building design process

Requirements management has been suggested by participants as a fundamental yet complex process in healthcare design, in which collecting, translating, and tracking requirements are key activities. Existing research already shed some light on this topic, regarding the diversity of requirements involved in healthcare projects (Tzortzopoulos *et al.* 2005, Braithwaite *et al.* 2015, Hicks *et al.* 2015), as well as the difficulties associated with managing and considering requirements in the design solution within a digital environment (Baldauf *et al.* 2021). Previous findings suggest the latter is affected by the dynamic nature of the design process (Luck *et al.* 2001, Tzortzopoulos *et al.* 2006, Krystallis *et al.* 2015), in addition to conflicting and evolving requirements observed during healthcare design (Green 1996, Darlington and Culley 2004, Kiviniemi and Fischer 2004, Kollberg *et al.* 2006, Sengonzi *et al.* 2009).

The lack of a common language between healthcare representatives (e.g. clinicians, nurses, and admin staff) and design teams has been mentioned by the participants as an issue in this context. It leads to difficulties especially during briefing stages, which can impact compliance during the entire design process. Kasali and Nersessian (2015) observed that healthcare representatives make use of a specific language that is generally incompatible with architects and other stakeholders involved in the design process. In fact, having a common language between designers and other stakeholders is described in existing literature (e.g. Green 1996, Shen *et al.* 2004) as fundamental to successful communication of needs and ideas, having a significant impact on the development of regulatory documents and, ultimately affecting design outcomes.

During early design stages, room layouts have been described as key design artefacts, supporting visualisation and mediation between stakeholders. This is aligned with findings reported by literature (e.g. Kasali and Nersessian 2015, O'Keeffe *et al.* 2015), as discussions fostered by design artefacts such as drawings, room layouts, mock-ups and similar representational practices support translating and unifying expertise in specific domains, representing expert feedback as well as enabling interdisciplinary assessment and collective consensus (Kasali and Nersessian 2015).

The iterative nature of the design process has been discussed both in terms of the iteration between requirements and design specifications, but also regarding the design–check cycle. Existing literature on design (e.g. Dorst and Cross 2001, Christensen and Ball 2016) suggests the iterative process of problem–-solution co-evolution is responsible for creating conceptual "bridges" between the problem space and the solution space, fostering creativity. From a design assessment perspective, this indicates that compliance processes should be more integrated into the fundamental iteration between requirements and design resolution than what has been reported in practice during the interviews.

Derogations have been highlighted by the participants as a key element in the healthcare design process in the UK. The analysis presented in the previous section indicates the focus of derogations has gradually shifted from clarifying and defining liabilities on non-compliances to a fundamental design driver, implying that the healthcare design culture might be under transformation. This could be a consequence of the constraining role of guidance documents identified by Hignett and Lu (2009) in this context, in which non-compliances had a significant influence on different aspects of healthcare projects, including impacts on duration and finances, as also noted by Shipton *et al.* (2014).

Automated compliance systems

The use of automated compliance systems has been mostly suggested to quantifiable and objective requirements and should focus on repetitive design activities. This reflects Simon's view on the fundamental relationship between humans and computers (Simon 1977). The referred author argues that in automated and technological environments, there is a higher demand for specialised and more skill-related human work, whereas computers are responsible for routine, repetitive and data processing tasks.

In the context explored by this paper, the above suggests that designers' time and efforts can be shifted to value-adding and creative design tasks. It also confirms what has been discussed by the participants, as well as recent literature findings, e.g. "the final aim of the automated rule checking should be a fully automated system that will free experts to focus on what really matters for buildings, such as safety, sustainability and high environmental performance" (Solihin and Eastman 2015, p. 70). It is important to highlight though, that time savings through the use of automation do not necessarily lead to improvements on creative and value-adding tasks. Conversely, this means that designers' time and efforts once dedicated to dull and repetitive tasks might shift to other design activities, which can involve value-adding work or not depending on complementary process changes.

From a process perspective, multiple compliance checking points have also been mentioned as needed to avoid rework, complementing findings from Tzortzopoulos *et al*. (2006), which suggested the impact of emerging and conflicting requirements became visible only after consultation meetings and assessment exercises, being a source of rework in design.

Despite the achievable benefits described above, requirements' subjectivity, as already discussed, has a large impact on the practical application of automated compliance, whereas automation has been suggested as challenging to design creativity. These two findings highlight the importance of considering designers' inputs and human reasoning to support automated compliance (Dimyadi *et al*. 2016, Hjelseth 2016, Mendonça *et al*. 2020, Amor and Dimyadi 2021).

This integration can be achieved in practice using hybrid approaches for automated compliance. They should be understood as human-guided systems (Amor and Dimyadi 2021), which are structured around human designers and automation simultaneously and complementary. The focus of hybrid approaches is on the development of supportive interfaces between human designers and digital technologies, which requires improved integration and consistency with designers' workflows and cognitive processes (Heumann and Davis 2019). They could be achieved, for example, by using external databases and rules embedded or connected to digital objects to support design (Hjelseth 2016), as well as by enabling user inputs (Dimyadi *et al*. 2016, Amor and Dimyadi 2021).

Considering the limitations of existing automated compliance systems, a set of recommendations for future software development emerged from the interviews. They represent needed changes to enable automated compliance from a design perspective and suggest that future developments should focus on different key aspects, presented in Table 5.

From the different understandings of automated compliance presented in the previous section, recommendations 1 (flag inconsistencies in real-time) and 2 (automated derogations) (Table 5) relate to the "substitute" understanding; recommendations 3 (pop-up dialogue window) and 4 (design informer) are associated with the "guidance" understanding; whereas recommendations 5 (built-in compliance) and 6 (automated simulations) relate to the "enhancement" understanding.

Contributions to theory and policy

The practical challenges associated with the use of the regulatory framework in the UK consist of major constraints for automated compliance. The confusion between guidance and statutory documents has been highlighted in existing literature (Hignett and Lu 2009, Mills *et al*. 2015), as well as concerns emerging from the plethora of documents (Beach *et al*. 2015). This adds to the existence of conflicting requirements, and the fact that they can be fuzzy and difficult to interpret and check (Lee *et al*. 2016, Beach *et al*. 2020, Solihin *et al*. 2020).

Requirements' subjectivity has been mentioned by existing research as a critical challenge in this context. It relates to (i) the way information has been originally incorporated in requirements' definition; as well as (ii) emerges from the interpretation of requirements. While the first is acknowledged as intrinsically associated with the nature of information (Nawari 2012a, 2019, Dimyadi and Amor 2013, Atoum and Otoom 2016); the second originates from the human interpretation needed to translate regulatory requirements into more objective sentences, so they can be used in automated approaches (Solihin and Eastman 2016). The above suggests that different layers of subjectivity are associated with regulatory requirements, and they are not mutually exclusive. In other words, while a

Table 5. Improvement needs on automated compliance systems.

Recommendation	Description	Quote	Related research
Flag inconsistencies in real-time	Promptly identification of any inconsistencies during design, supporting quick fix of non-compliances.	*"Having a system that flags a possible issue; that would be useful. […] Everything, you know, takes forever, especially to design. There's a design change and then, you know, to capture that change and possibly, if it's non-compliant, for example, it would notify us there" (participant 11)."from HBNs and HTMs if it says this room is too small or it's too big, that would be helpful. […] If you had something that as you drew it and said right okay that's compliant, and it came out and just told you what the answer was at the end in terms of compliance that would be quite useful" (participant 1)."If we've got something that is actually checking elements of HBNs and HTMs so they're not having to drill down into the nitty-gritty. If they've got a report or a plan that flags up rooms that are of concern, or areas that are of concern" (participant 2).*	"At some point in the future, rule checking may have extended reporting capabilities. For example, the reporting could be back to the host application and model, allowing quick correction"(Eastman *et al.* 2009) "Also, rule systems implemented locally could do the error reporting in the authoring tool, facilitating much reduction in the correction iteration cycles"(Eastman *et al.* 2009)"The rule-checking process may also be more a dynamic process which is executed more frequently or whenever a change occurs to a model"(Melzner *et al.* 2013)
Pop-up dialogue window	Use complementary information from regulatory documents embedded into digital design modelling tools to support improved design decision making.	*"If it's not prescriptive [requirement], then embed the decision-making process inside what you can do. Have a dialogue or pop-up window that says, right you've placed this. These are your options based on what you can do" (participant 10).*	"Insufficient emphasis is given to the characteristics of a standard as a design aid" (Toms 1988) "Design standards should foster creativity and innovation, supporting and enhancing the imaginative decision making of designers, rather than overly controlling or inhibiting it" (Von der Tann *et al.* 2018)
Design informer	Use of a hybrid approach to support designers to improve decision-making. This could be understood as a further development from the previous item (pop-up dialogue window).	*'You almost need a partner, the non-human partner, the robot who says: hold on a minute, three meetings ago somebody said you needed to be green so think about that, and then you could say well actually I've thought about this and I've looked at all the stuff and I'm going to make it red. […] and that digital listened to everything, then translated it using deep learning and AI into keywords and things like that, and that was recorded.' (participant 6)*	"Systems should exhibit some form of 'intelligence' in assisting designers in their work" (Galle 1995)
Built-in compliance	Incorporating compliance through standard room layouts and parameters in objects to improve overall compliance of healthcare designs.	*"[standard] designs being made available, being shared with the clinical teams, and yeah there might be some fine tweaks, but you don't have to kind of start every scheme from scratch" (participant 5)."I'm kind of imagining when you have families and you have sort of components and you import them all and they come with an embedded sort of parametric and decision-making logic, whereby you try and bring another component or family into its zone or round it, and it goes: you can't do this" (participant 10).*	"Smart objects are objects which have embedded rules that respond to change in other selected objects. The essence is that the smart objects automatically respond to pre-defined changes in the design" (Hjelseth 2016)
Automated derogations	Development of automated derogation schedules based on the identification of non-compliances in design and with support of evidence.	*"Derogation schedules would be very useful, very, very useful. We want to derogate here because of that, and then you fill it in saying what your client wants; or, oh now we didn't realise that is derogation, better tell the client" (participants 3 and 4)."[…] and whether that's linked to a derogation schedule, or it automatically populates derogation schedule for you, is a definite a benefit for the client because they'll see straightaway.' (participant 2)*	"A link between requirements and design objects can help designers to understand the interaction between requirements and design solutions better. It also helps the project managers and clients to manage the requirements and to evaluate the design solutions compared to requirements" (Kiviniemi 2005)
Simulation of adjacencies	Development of simulations for adjacencies at early design stages, aiming to improve users' awareness of the design.	*'I would like to actually simulate those adjacencies very quickly and playback in real-time, and in a virtual sense of what their [users, clinicians] experience would be before we put pen to paper, we can actually model and simulate that' (participant 9)*	"A fully integrated model [healthcare building design] enables, for example, simulations of the patient and internal staff flows and their activities and interrelations, as well as analyses of the materials distribution processes in the building" (Caixeta and Fabricio 2021)"The interviewees identified the tasks they perform when looking at 'what-if' scenarios during the design process. Aspects such as activity projections, patient flow, room adjacencies are some of what was identified by the interviewees to develop their business case" (Krystallis *et al.* 2015)

requirement can be subjective because it contains abstract or inaccurate information (i), its interpretation can also be subjective (ii), resulting in a convoluted outcome that ultimately can diverge from the original intent expressed by the requirement.

The existing healthcare building design regulatory framework is understood by participants as outdated and unfit for purpose. Toms (1988) identified that regulatory documents are lengthy and need to be reviewed and constantly improved. Despite dating back to more than 30 years, these issues appear to be similar to what is reported in the current regulatory framework in the UK.

In light of the challenges discussed in the previous section and summarised above, key improvement needs on the regulatory framework have been suggested by the participants. They are mostly associated with the appropriate digitisation of the regulatory framework, highlighting the gap between the existing documents, current digital design approaches and automated compliance. Key improvement needs are presented in Table 6 through recommendations, their description, example quotes from the interviews, as well as linking to existing research related to each topic.

Final remarks

Conducting a series of interviews within the healthcare building design context allowed answering the main questions proposed by this study. The analysis carried out in this paper is based on the semi-structured interviews developed as part of a research project and is limited to the participants' perspectives on the topics being discussed.

Findings suggest that the regulatory framework influences the design process in all phases, with specific documents being more relevant according to different design stages. There is a large gap between the regulatory framework and the digital design context, especially related to automated compliance. This is due to (i) the format in which guidance documents and standards are presented to designers, and, consequently, how they are used in practice; and (ii) their content and how information is originally included in regulatory requirements. This confirms existing literature findings, indicating that the way documents are written, developed and reviewed compromise their practical use (Toms 1988, Solihin and Eastman 2016, Von der Tann *et al*. 2018). Further revision of the framework was mentioned by participants not only as needed, but as essential to enable a degree of automation. Participants evidenced key aspects that would need further development and how they could be achieved through needed improvements and recommendations (i.e. sentence structuring, searchability, interactivity, intelligibility, cloud-based integration).

By making better use of automated compliance approaches, designers would not need to focus on repetitive activities, whereas their time and efforts could be shifted to the creative aspects of design and improved decision-making. Nevertheless, the complexity of the healthcare building design process makes automation difficult to be achieved without specific developments in this context, as well as by better involving designers in the creation of new tools and software applications.

We found that designers involved in healthcare projects perceive automation differently to support compliance. Findings describe different perspectives in which automated approaches are understood for this purpose, by substituting, guiding, or enhancing designers' activities. In this context, automated compliance should not only support "assessing" or "checking" design outputs, but also aid better decision-making using multiple and hybrid approaches. By providing a set of key needed improvements that should be targeted while creating or updating software within the context explored in this paper (i.e. flag inconsistencies in real-time, automated derogations, pop-up dialogue window, design informer, built-in compliance, simulation of adjacencies), designers also demonstrate their willingness to engage in such developments.

The discussion section highlighted key contributions to theory, practice and policy arising from the paper. Both sets of improvement needs presented in Tables 5 and 6 relate to the digitisation of design and compliance processes, being interdependent to a certain level. While further revisions of the regulatory framework can minimise mistakes and misinterpretations by digitising information, they also help to ensure regulatory documents are fit for purpose considering the digital design context. Improvement needs on software development would only be effective if regulatory information used to support design and compliance is compatible with the methods used in practice. Future research can better explore this interdependency aiming to address the limitations of this study, by expanding their scope to also include the perspectives from clinical teams and healthcare planners, for example.

There is an agreement between participants that requirements' subjectivity is essential to enable creativity in design, becoming more important in the healthcare

Table 6. Improvement needs on the regulatory framework.

Recommendation	Description	Example quote	Related research
Sentence structuring	The regulatory framework should be reviewed aiming to improve sentence structuring in a way as to make it computer-readable.	*"So, modifying the building code so that it will become computer-readable is an essential step for semi-automated design and code checking. Considering the slow adoption of technologies in the AECO industry, I don't believe that full automation of the design or code checking will be possible in the next few decades" (participant 7).*	"Complex rules typically found in building codes are a combination of several aspects that contribute to their complexity. They involve the language structure, the domain knowledge embedded in the rules, and their logic structure. Added to those technical aspects of the rules is the knowledge of human experts" (Solihin and Eastman 2016)
Searchability	The structure of documents should enable a quick search of specific requirements being consulted.	*"At the moment the way they [Building Regulations] are developed is horrendous, they take a long time to change, and because they are just a document, they are not even searchable, and the process of updating from A to K in documents takes a long time" (participant 6)."Yeah, well, I mean it's always handy having a text-based document that you can refer to, and search through" (participant 11).*	"Current process could improve significantly if designers could easily find the requirements related to their on-going task" (Kiviniemi 2005)
Interactivity	Documents should be interactive, less static, and present additional information associated with each requirement, so further understanding is achievable.	*"And if there was some kind of extrapolation and a digital PDF, we could click on it and understand the logic behind it, then you might be able to interrogate it a little bit further" (participant 10)."It does need to be an interactive system, even if it's something as simple as clicking on the part and it brings up a standard detail, […] providing approved ways of achieving the requirements in the document. Examples are what I really want to see as an architect" (participant 11).*	"Examples and images can foster imagination and better support design" (Toms 1988) "A link between requirements and design objects can help designers to understand the interaction between requirements and design solutions better" (Kiviniemi 2005)
Intelligibility	Documents should become "intelligent", being integrated into automated compliance systems.	*"I think the current impact at the moment of the documents is restrictive, as they are currently produced, I think with the option of an automated compliance process and intelligent documents, […] you could go right to the extreme of the intelligent ward, for example.' (participant 9)*	"Smart or intelligent code is referred to as the computable digital format of the building codes that allow automated rule and regulation checking" (Nawari 2013)
Cloud-based integration	Requirements should be stored in cloud-based platforms to better suit the digital design environment and foster integrated developments.	*'It needs to have that cloud-based integration with the documentation of standards for it to be fully end-to-end, and that has not to be one software, it just is a common design process and methodology that allows systems to become un-siloed and for standards and documents to become intelligent. And I think that's a key short-term driver that needs to be done" (participant 9)."The main thing for documents in the guidance is having them all filtered into one location to go through during the process. You've already got a matrix of decision-making for building regulations, and a separate matrix for HTMs and HBNs, and trying to interweave those together you're just sort of massively compounding the possibilities" (participant 10).*	"A logical solution is a data interface, a link between the requirements and the design solutions, which more effectively connects the requirements to the design process" (Kiviniemi 2005)

context because of its relationship to innovation. We have identified that different layers of subjectivity are associated with regulatory requirements and design compliance. Despite this understanding, current automated compliance approaches fail in considering subjective requirements. From a research perspective, there has been too much focus on prescriptive and objective requirements, with poor consideration of subjectivity and creativity, which are essential and intrinsic to design (Crilly 2019), having a major impact on the use of automated compliance approaches in practice as highlighted during the interviews.

Participants believe that requirements' subjectivity needs to be managed – and not eliminated – from the digital healthcare design process. In this context, automation is understood as liberating, as opposed to stifling design. This suggests the paradox involving subjectivity, creativity and automation exists only when automation is understood as a substitute to human designers, whereas the focus on using automation through guidance and enhancement has been poorly explored in this context so far.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Notes

1. From a methodological standpoint, a questionnaire is a different data collection instrument in contrast to semi-structured interviews. It has limitations in terms of interacting with the interviewee and making follow-up questions. Considering the purpose of this paper, outcomes of Interview 6 have been analysed in the same way as the other interviews.
2. Parametric modelling "represents objects by parameters and rules that determine the geometry as well as some nongeometric properties and features. The parameters and rules can be expressions that relate to other objects, thus allowing the objects to automatically update according to user control or changing contexts." (Eastman et al. 2011, p. 31)
3. Generative design can be understood as a "designer driven, parametrically constrained design exploration process" (Krish 2011, p. 90)

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