Ransolin, N., Saurin, T.A., Formoso, C.T., Clay-Williams, R., Rapport, F. (2024). Built environment design knowledge for resilient healthcare. In D. B. Costa, F. Drevland, & L. Florez-Perez (Eds.), *Proceedings of the 32nd Annual Conference of the International Group for Lean Construction* (IGLC32) (pp. 60–71). doi.org/10.24928/2024/0186

BUILT ENVIRONMENT DESIGN KNOWLEDGE FRAMEWORK SUPPORTIVE OF RESILIENT HEALTHCARE

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ABSTRACT

Although the evidence-based design (EBD) literature investigating the influence of the built environment (BE) on health services performance and outcomes is extensive, its contribution to resilient healthcare is scarce. This work presents a framework of BE design knowledge supportive of resilient healthcare. Firstly, a systematic literature review based on EBD, complexity, and resilience resulted in generic BE design knowledge that represented the role of BE in supporting resilient healthcare at different levels of abstraction. Next, the knowledge was used for thematic analysis in case studies in two teaching hospitals, tailored to workflows that occurred in the connecting areas to and from an intensive care and other hospital units of a large public hospital in Brazil and the surgical service of a private hospital in Australia. Joint findings allowed the development of a framework hierarchically composed of four meta-principles, seven principles, seven prescriptions, and 181 practical examples emphasizing a systems perspective that considers intra and inter-hospital workflows and areas. The resulting knowledge guides designers of both BE and operations phases during decision-making to support resilient health services. As a limitation, the framework was not applied during those phases, representing one of the main suggestions for future work.

KEYWORDS

Evidence-based Design, Built environment, Complexity, Resilient Healthcare.

INTRODUCTION

Health services are Complex-Socio Technical Systems (CSSs) in which care provision is possible due to dynamic interactions between human, technical, and organisational elements influenced by the external environment (Braithwaite, 2018). An emerging property that arises from these interactions in CSSs is resilient performance (RP), a phenomenon that, in the context of health services, is investigated underneath the realm of resilient healthcare - i.e., *"the ability of the healthcare system (a clinic, a ward, a hospital, a county) to adjust its functioning prior to, during, or following events (changes, disturbances or opportunities), and thereby sustain*

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required operations under both expected and unexpected conditions" (Hollnagel et al., 2013). In the myriad of interactions, the built environment (BE) is a technical system that supports activities and shapes the relationships between processes, technologies and stakeholders (Hicks et al., 2015; Hollnagel, 2014; Real et al., 2017). Therefore, BE should support resilient healthcare, as its relevance for the performance of health services has been acknowledged by several studies on BE influence on both patient outcomes and caregivers´ performance (Real et al., 2017; Machry et al., 2021).

The body of knowledge on the influence of BE on health services has been produced under the umbrella of evidence-based design (EBD) (Ulrich et al., 2008; Zhang et al., 2017). The EBD literature focuses on the BE impacts on efficiency and safety of care provision from factors such as privacy, noise, light, access to outdoor spaces, accessibility, and layout (to the external environment, accessibility, and layout (Rybkowski; Greer et al., 2021). From the viewpoint of lean construction, EBD is useful for generating value to stakeholder - e.g., patients and staff members - and workflows - e.g. health services (Zhang et al., 2016). Nonetheless, EBD studies are commonly criticized for neglecting the complexity of health services, overlooking the interactions that occur in the BE and missing the need to support RP (Halawa et al., 2020; Łukasik and Porębska, 2022). From a resilient healthcare perspective, this EBD drawback is a failure to acknowledge the gap between work-as-imagined (WAI) in design and protocols and work-as-done (WAD) in reality (Ransolin et al., 2020; Machry et al., 2021; Joseph et al., 2022). This gap arises from the everyday variability of complex systems, a condition that requires RP – which is commonly unveiled in the successful outcomes of WAD and highlighted by resilient healthcare (Bueno et al., 2021). However, EBD tends to produce knowledge based on the WAI formalised in guidelines rather than the WAD on site, which leads to a lack of comprehension of the complexity and resilience during the design of health systems. Moreover, while EBD is a source of knowledge for designers, it is bound to a specific context and does not provide a standard for repetition, which contributes to the fragmentation of EBD knowledge (Zhang et al., 2016).

Therefore, *the aim of this paper is to propose a framework of BE design knowledge supportive of resilient healthcare*. It is based on a systematic literature review (SLR) and two empirical studies carried out in different hospital units, on in Brazil and the other in Australia. The SLR investigated EBD studies on complex socio-technical systems and resilient healthcare resulted in a generic BE design knowledge supportive of resilient healthcare (Ransolin et al., 2022). The corresponding knowledge is structured according to different levels of abstraction, from high-level general design guidance, to low-level practical solutions that are highly context-dependent. Then, the knowledge was applied as a heuristic device for data analysis, being tailored to the specific context of two empirical studies. Thus, the case studies investigated the WAD of hospital workflows in (i) the connecting areas to and from an intensive care unit (ICU) of a large public hospital in Brazil (Ransolin et al., 2024a), and (ii) the surgical service of a private hospital in Australia (Ransolin et al., 2024b). This investigation is relevant for design management, a traditional lean construction topic that can explore the resulting framework to develop theories and practices for designing resilient healthcare.

DESIGN KNOWLEDGE FOR RESILIENT HEALTHCARE

The myriad of complex interactions in health services cannot be completely controlled and anticipated, but they can be partially subject to the influence of design (Plsek & Greenhalgh, 2001; Wachs et al., 2016). Similarly, resilience emerges partly from CSS self-organisation dynamics and partly from intentional design decisions to support it. This latter is associated with the concept of Design for RP, defined as "*the use of design principles to support integrated human, technical, and organisational adaptive capabilities*"(Disconzi and Saurin, 2022).

Albeit not addressing RP, the EBD framework proposed by Zhang et al. (2019) was devised according to design principles (e.g., 'comfortable environment'), followed by design parameters (e.g., 'light'), which gave rise to sub-parameters (e.g., 'daylight'). Saurin et al. (2013) developed guidelines for coping with complexity based on resilience theory (Table 1), so they were used as a point of departure for this research work that applies to health services.

Table 1: Guidelines for coping with complexity and their definitions (Saurin et al., 2013; Bueno et al., 2019).

	Guidelines for coping with complexity	Definitions
1	Supporting visibility of processes and outcomes	Promotion of real-time visibility to either formal or informal work practices for a user-intuitive CSS functioning (Clegg, 2000; Galsworth, 2017).
2	Designing slack	Human or technical for absorbing uncertainty - i.e., spare resources that can be activated when necessary (Nohria & Gulati, 1996; Formoso et al., 2021).
3	Encouraging diversity of perspectives when making decisions	Diversity of perspectives helps to manage uncertainty and requires high levels of trust, low power differentials, and apt decision-makers (Page, 2010).
4	Monitoring and understanding the gap between work-as-imagined (WAI) and work-as-done (WAD)	Awareness of the daily variabilities in performance and outcomes implied in CSSs. The reasons and consequences of this gap should be investigated (Hollnagel, 2017).
5	Monitoring unintended consequences of improvements and changes	Interventions interact between themselves and the environment, creating negative or positive unintended consequences (Perrow, 1984; Ogrinc et al., 2015).

The design knowledge framework presented in this paper comprises meta-principles (i.e., the guidelines of Saurin et al., 2013), principles, prescriptions, and practical examples. Design principles are at a higher abstraction level and refer to a group of prescriptions that share similar goals (Kuechler and Vaishnavi, 2012; Ransolin et al., 2022). According to Vaishnavi and Kuechler (2015), a design prescription is a suggestion for action in a given circumstance to achieve an effect. Instantiations of the prescriptions in a particular context are practical examples at the lowest level of abstraction (Ransolin et al., 2022).

RESEARCH METHOD

RESEARCH DESIGN

This research work used qualitative methods as their utility to uncover complexity has been recognised (Rapport and Braithwaite, 2020). Firstly, a SLR explored how the EBD literature addresses complexity and resilience in BE health services (Ransolin et al., 2022). Furthermore, case studies allow for developing both generalizable and context-specific knowledge (Yin, 2017), which is consonant to develop BE design knowledge across different levels of abstraction. Then, two case studies were successively conducted in teaching hospitals, investigating the particularities of workflows in different hospital settings. The first case study was conducted in a large (around 6,000 employees) public and tertiary hospital in Southern Brazil, where we paid attention to the interactions between an adult ICU and other hospital units - e.g., in-patient wards and non-clinical areas such as warehouse - across a three-building complex (Ransolin et al., 2024a). The second case study was undertaken on the first floor of a medium-sized private hospital in NSW, encompassing elective surgical service flows (Ransolin et al., 2024b). Both empirical studies followed two major stages: (i) characterisation of the health service flows and BE, and (ii) development of the design knowledge. The joint analysis of the findings from the SLR and the case studies allowed the identification of emerging patterns that gave rise to a design knowledge framework to address the main research objective.

DATA COLLECTION AND ANALYSIS

In Ransolin et al. (2022), an SLR followed the steps proposed by the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) (Moher et al., 2009), which are: 1) identification of the papers; 2) screening; 3) eligibility; and 4) inclusion. From 2412 records identified from seven databases and five manual inclusions, 2220 were screened, 397 were fully assessed, and 43 papers were selected for qualitative analysis. The search string was composed of variations of keywords related to the following domains: study object (e.g., built environment, EBD); context (e.g., health services); approaches (e.g., complexity, resilience); outcomes (e.g., safety, well-being); and stakeholder (e.g., patients, staff). The selection of publications was not limited by year; papers were filtered in English and related to similar areas (e.g., engineering, social science, business and management, arts and humanities). The screening considered four exclusion criteria: (i) non-scientific texts; (ii) conference proceedings; (iii) literature reviews; and (iv) content unrelated to healthcare facilities (e.g., ethical aspects), or the research aims (e.g., risk analysis). In the eligibility step, the resulting publications were scanned in order to exclude papers that did not contain any of the following keywords in the full text: Complex*; Resil*; Flex*; Adapt*; Flow; Evidence-based Design (EBD). Finally, the included publications were fully analysed.

Empirical data collection was carried out by the first author after the ethics committees of both hospitals approved the respective research projects, and participants provided written informed consent before being interviewed. Table 2 presents the total hours of data collection in each case study, according to the sources of evidence used. In total, 133 hours of data were gathered using all data collection techniques in both empirical studies (Ransolin et al., 2024a/b).

Table 2 – Total of data collection (hours) of case studies associated with the sources of evidence.

Data collection	Sources of evidence				
	Document analysis	Non-participant observations	Semi-structured interviews	Meetings with hospital staff	Total (hours)
1st case study – ICU connecting areas (Ransolin et al., 2024a)	-	50	30	1	81
2nd case study – Surgical service (Ransolin et al., 2024b)		30	16	6	52
					133

Documents considered for analysis were Brazilian and Australian BE design regulations, guidelines, and architectural floor plans of both hospitals of the case studies. Non-participant observations were conducted during visits and walkthrough sessions to observe workflows performed by frontline staff members. Semi-structured interviews involved two main questions: (1) Could you give an overview of your daily work and the relevant workflows for this hospital unit? and (2) how does the BE facilitate or hinder everyday work regarding these workflows? Please illustrate these implications with a situation experienced by you or a colleague.

Interviewees were divided into five categories: management, administrative/supporting, engineering, clinical assistance, and patients/family members. Meetings with hospital staff helped identify interviewees, defining workflows and areas from which data would be collected, and presenting and discussing the design knowledge framework.

Data collected in the SLR and the case studies was subjected to a content analysis (Pope et al., 2000). This process encompassed familiarisation, identifying themes, coding, charting, mapping and interpretation and was performed successively according to the development of each study. Familiarisation involved multiple readings of primary and secondary data - i.e., papers selected in the SLR, regulations, interview transcripts, and observation notes. Themes were defined previously and imposed for analysis as a heuristic device, being performed successively, allowing tailoring it to each study context. In the SLR (Ransolin et al., 2022), themes corresponded to the guidelines for coping with complexity – i.e., design meta-principles (Table 1). Next, the first case study (Ransolin et al., 2024a) considered the seven design principles developed in the SLR as themes (Ransolin et al., 2022). Then, the second case study (Ransolin et al., 2024b) used as themes for analysis the design prescriptions developed in the previous case study (Ransolin et al., 2024a). Figure 1 illustrates the selection of themes for data analysis in each study of this research work, which corresponded to the levels of the design knowledge framework.

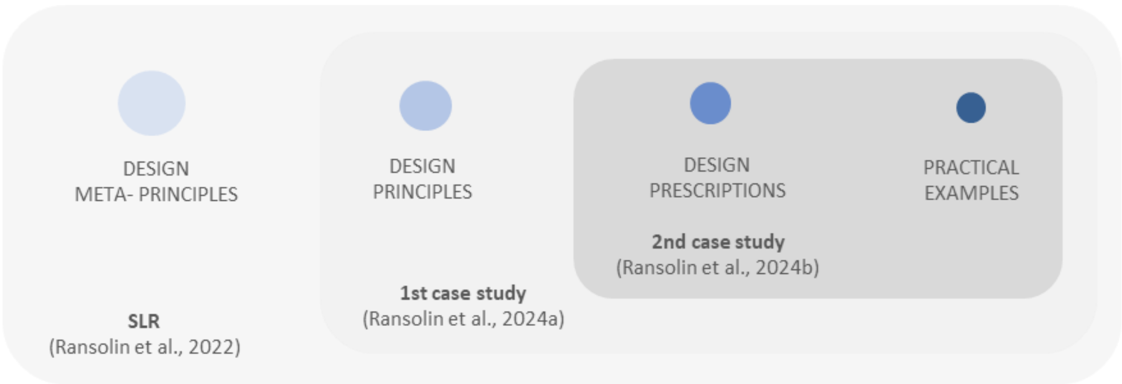

Figure 1: Thematic analysis of the studies in a successive and complementary order according to design knowledge framework levels.

Data coding was performed independently by at least two authors (e.g., NR and TAS) according to the themes defined for each study, based on agreements from meetings to achieve consensus. In the RSL, the coding stage was carried out in four steps with different levels of abstraction corresponding to design meta-principles, design principles, design prescriptions, and practical examples (Ransolin et al., 2022). The charting stage corresponded to the synthesis of findings from the previous stages of content analysis. In the RSL, the knowledge structure was established, representing the different levels of abstraction – i.e., design meta-principle, the corresponding principles, prescriptions and practical examples (results section). In the case studies, findings were schematically represented in Tables that associated the practical examples with each design prescription, tailored to different health services. Lastly, the mapping and interpretation stage related to the discussion of design knowledge resulted in each of the studies in light of the EBD and resilient healthcare literature. Details of methodological procedures can be found in the respective sources (Ransolin et al., 2022; Ransolin et al., 2024a/b).

RESULTS

Figure 2 presents the BE design knowledge framework for resilient healthcare. At the highest abstraction level, the four design meta-principles corresponded to the complexity guidelines

(Table 1). The seven design principles are applications of the guidelines for the BE in health services (Ransolin et al., 2022). In the two lowest abstraction levels, empirical data were linked to the structure, being useful in structuring the presentation of the findings in Ransolin et al. (2024a/b). The design prescriptions correspond to the application of the principles to a context. There is no one-to-one relationship between principles and prescriptions – e.g., the same prescription emerged from multiple principles. The resulting seven design prescriptions are tailored to the context of the case studies (Ransolin et al., 2024a/b). Then, the last framework level is composed of 181 practical examples of real situations where the BE is supportive of resilient healthcare in the health settings, linked with hospital workflows and areas (Ransolin et al., 2024a/b).

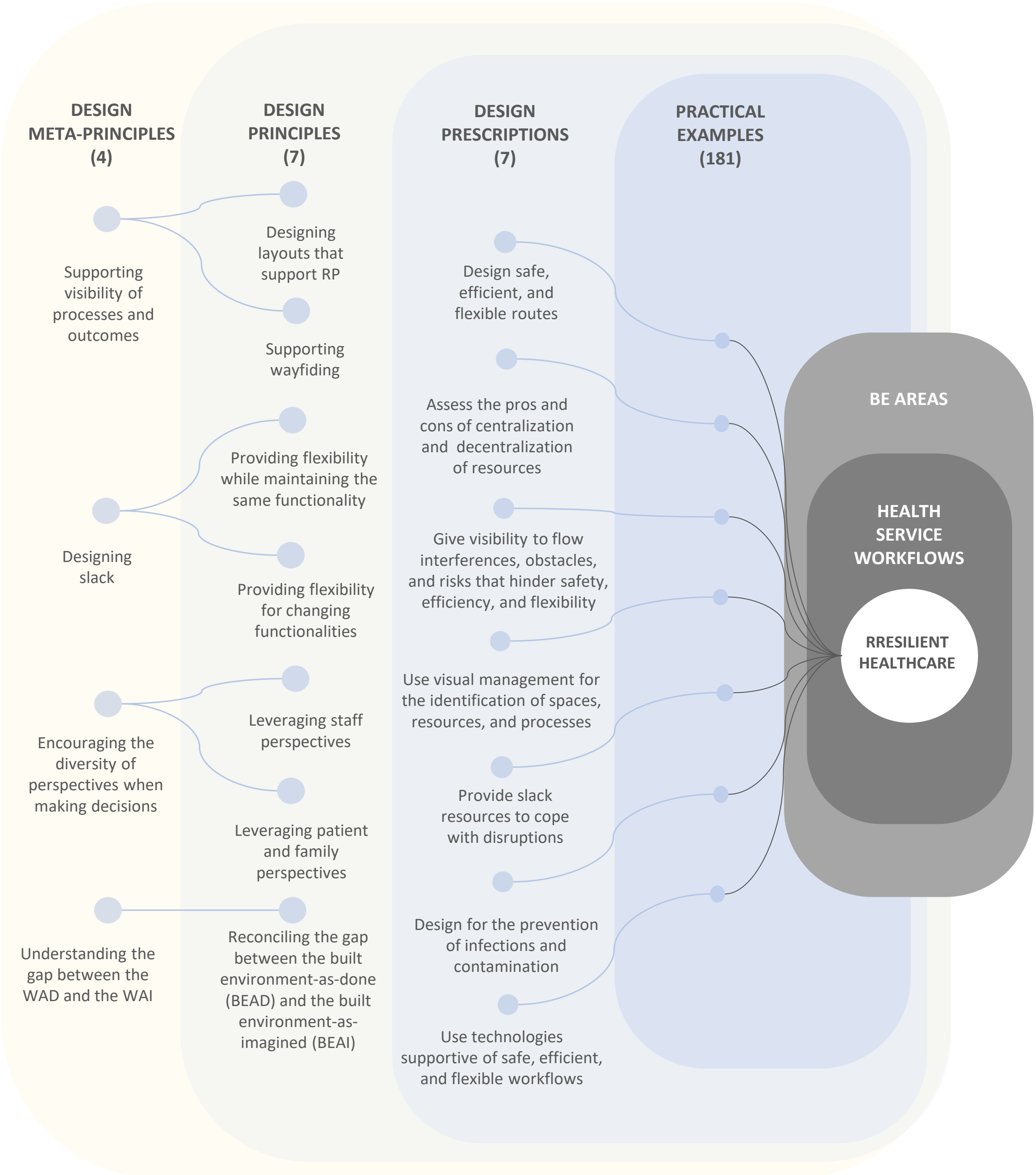

Figure 2: Framework of BE design knowledge for resilient healthcare.

The seven design principles were established in the SLR (Ransolin et al., 2022). The first design meta-principle - supporting visibility of processes and outcomes - derived into two design principles: ‘designing layouts that support RP’ and ‘supporting wayfinding’. The former is illustrated as BE configurations that improve the efficiency of operations and support users´ safety, well-being and interactions. Supporting wayfinding is associated with providing orientation and navigation of users across BE in health services. The second design meta-principle - designing slack - contributed to the design principles: ‘providing flexibility while maintaining the same functionality’, e.g., adaptation, customisation, and expansion, and ‘providing flexibility while changing functionalities’, i.e., changing the main purpose of spaces.

Then, the third design meta-principle - encouraging diversity of perspectives when making decisions - gave rise to two design principles related to ‘leveraging patient and family perspectives’ and ‘leveraging staff perspectives’. The fourth design meta-principle - monitoring and understanding the gap between work-as-imagined (WAI) and work-as-done (WAD) – is translated into ‘reconciling the gap between the built environment-as-done (BEAD) and the built environment-as-imagined (BEAI)’, as the BE design (i.e., BEAI) should be strongly based on the understanding of how people use the BE in reality (BEAD). Lastly, for the fifth design meta-principle - monitoring unintended consequences of improvements and changes - to be effective, this monitoring demands the application of all the design principles above mentioned.

The resulting seven design prescriptions are listed in Figure 2 and were refined to the context of hospital workflows in the ICU connecting areas and surgical services case studies – i.e., two empirical studies (Ransolin et al., 2024a/b). Table 3 presents similarities between some practical examples from the case studies to illustrate the relevance of the design prescriptions for different contexts.

The first design prescription is exemplified by designing direct connections between hospital units in different buildings - e.g., walkways on all floors (1st case study). Similarly, direct connections are necessary to promote ease of transfer and access among surgical phases, using back-of-house corridors – e.g., the ICU should be close to operating rooms to ensure quick patient transportation (2nd case study). Freeing corridor width according to requirements is also present in practical examples from both case studies, as follows: place workstations in the corridors while maintaining the minimum free width of corridors set by regulations (1st case study) and comply with corridor width requirements for clinical areas – e.g., corridors should be wider enough to fit ICU beds that are larger than regular ward beds (2nd case study). The second prescription encompasses practical examples from both case studies related to having a mix of centralised and decentralised storage to share resources among hospital units. For instance, the 1st case study shed light on the importance of designing supporting areas that serve more than one hospital unit, avoiding duplication of resources, and sharing expensive and scarce equipment or infrastructure between ICUs and other hospital units - e.g., tomography, defibrillators, crash carts, pharmacy. In turn, the 2nd case study presented the example of designing centralised storage for general items shared among surgical phases and decentralised storage areas for specific surgical items – e.g., drugs with a higher risk of misuse must be stored in a locked cabinet shared among the operating rooms, allowing control and ready access nurses. The third design prescription is associated with practical examples of preventing interactions between dirty and clean flows. The first case study illustrates the use of dedicated lifts for patients to avoid flow interferences and the design of separate storage for dirty clothes from clean clothes (1st case study). It is also exemplified by prioritising patient flows in corridors and lifts and the signage for the dedicated use of lifts for patient transportation during busy surgery days (2nd case study). This prescription also emphasizes the visual demarcation for equipment storage based on practical examples of signalising an allocated area for parking supply carts and unloading materials near the ICU pharmacy (1st case study) and demarcating visually with lines or colours on the floor and walls to indicate where equipment can be stored (2nd case study).

Table 3 – Illustration of similarities between practical examples from each empirical study (Ransolin et al., 2024a/b).

	Design prescriptions	**Similarities between practical examples from each empirical study** **1st case study - ICU connecting areas** **(Ransolin et al., 2024a)**	**Similarities between practical examples from each empirical study** **2nd case study - Surgical service** **(Ransolin et al., 2024b)**
1	Designing safe, efficient, and flexible routes	Design direct connections Free corridor width according to requirements	
2	Assess the pros and cons of centralisation and decentralisation of resources	Design a mix of centralised and decentralised storage to share resources among hospital units	
3	Give visibility to flow interferences, obstacles, and risks that hinder safety, efficiency, and flexibility	Prevent interactions between dirty and clean flows Provide visual demarcation for equipment storage	
4	Use visual management for the identification of spaces, resources, and processes	Design an intuitive signage	
5	Provide slack resources to cope with disruptions	Provide backup for expansion *Design multiuse spaces*	
6	Design for the prevention of infections and contamination	Distribute dispensers and PPE consistently Give visibility to sterile zones	
7	Use technologies supportive of safe, efficient, and flexible workflows	Provide devices to hold and open doors Avoid patient changes between stretchers Implement alerts to aware staff	
	Practical example “design multiuse spaces” from each case study	 Large warehouse for the storage of equipment and supplies during the COVID-19 pandemic	 Perioperative patient bay being temporarily used as equipment storage

The fourth prescription is related to practical examples from both empirical studies on designing intuitive signage. It can be achieved by self-explanatory direction signage for hospital flows and areas - e.g., using colours and symbols (1st case study) and progressive information disclosure at the right time to minimise the number of decisions required by users (2nd case study). The case study in the surgical service also presented practical examples of strategies to reinforce people’s mental maps by demarcating boundaries of different with singular elements. The fifth prescription is connected with practical examples that will strengthen the need to anticipate backup for necessary expansions – e.g., ICU bed capacity during crises (1st case study), and extra inventory spaces (2nd case study) - and design multiuse spaces – e.g., spaces that can also serve as a warehouse of equipment and supplies during demand fluctuations (1st case study), and support areas that allow conversion to operating rooms (2nd case study). The sixth design prescription is grouped with examples from both case studies that share the concern of distributing dispensers and PPE and giving visibility to sterile zones. The 1st case study illustrated the need for placing hand sanitizers in the corridors and at the entrance of the hospital units and designing dedicated routes between restricted areas – e.g., transit of sterilized materials and access to the warehouse elevator. In turn, the 2nd case study underlined the consistent distribution of dispensers and PPE with ease of access across the service and using disposable drapes to cover the operating table, trolleys, light handles, and robot arms to make sterile zones visible.

The last design prescription is associated with practical examples that share three similar topics. Providing devices to hold and open doors is illustrated by the need to temporarily keep the fire door open during the team's passage in an emergency, e.g., a patient resuscitation call (1st case study), or to automatically open doors in high-traffic areas, e.g., between the operating room and induction room (2nd case study). Avoiding patient changes between stretchers is another shared topic of this prescriptions, illustrated by the use of flexible ICU beds that should accommodate the attachment of equipment for critical patient transportation between hospital units and allow procedures in the surgical centre (1st case study). The need for specific patient stretchers could be anticipated in the admission to reduce patient handling and stretchers in corridors – e.g., if a bariatric patient is admitted, a larger bed should be provided in the preoperative phase (2nd case study). Finally, implementing alerts to make staff aware is illustrated by notifications to indicate when storages of waste are full and need to be collected at the units (1st case study) and by call systems with buttons inside operating rooms to signalise the supporting areas that orderlies and clinical staff are needed and warn the surgical team that the patient waiting in the induction room is ready to enter the operating room (2nd case study).

The 1st case study, developed in the ICU connecting areas, linked 63 practical examples that were associated with 11 hospital workflows, as follows: people (resuscitation, exams, admission, discharge, visitors) and supplies (drugs and medical materials, dietary, sterilized materials, cleaning, clothing, waste) (Ransolin et al., 2024a). In turn, the case study on surgical services is associated with 60 practical examples with six main flows – i.e., patient/family, staff, supplies, equipment, sterile instruments and materials, and waste (Ransolin et al., 2024b). The complete list of the practical examples from each case study with details of their sources of evidence and associations with workflows and BE areas can be found in the respective papers.

DISCUSSION

Resilience should be supported across all levels of health services, namely macro (e.g., national healthcare system), meso (e.g., hospital workflows), and micro levels (e.g., hospital units) (Berg et al., 2018). However, understanding the interactions between these levels has been an under-explored topic (Ellis et al., 2019). Therefore, the framework is an original contribution to integrating the BE design knowledge across health service levels. At the micro level, the framework is relevant for the surgical services while considering the implications for the meso level when discussing the interactions with other hospital units – e.g., operating rooms should be close to the ICU to ensure quick patient transportation. At the meso level, the framework was developed for the hospital workflows in the interconnecting areas to and from the ICU and other hospital units such as corridors and warehouse. At the macro level, the framework can be useful for identifying BE requirements supportive of resilient healthcare.

Integrating these levels and the interconnection of elements at different levels of abstraction in the knowledge framework provide insights to orient decision-making – e.g., trade-offs between design prescriptions to assign priorities for interventions. Rather than a template for compliance, the framework should help to identify practical examples of the BE implications to RP that otherwise could have remained concealed in the successful WAD. The investigation of the WAD was possible through qualitative methods, in which case study stages and methodological techniques can be replicated in other health settings and resilient healthcare studies.

CONCLUSIONS

This paper presented a framework of BE design knowledge supportive of resilient healthcare based on a SLR and two empirical studies, on in Brazil and the other in Australia. It is hierarchically composed of four meta-principles, seven principles, seven prescriptions, and 181 practical examples. An international readership of academics and practitioners can benefit from the framework, as different contexts are discussed in light of complexity and resilient healthcare. The framework is expected to guide both BE and operations designers in health services.

Some limitations of this work must be highlighted: (i) the framework was conceived based on a resilient healthcare perspective, focusing on everyday work; thus, disasters were considered out of the scope of this work; (ii) the framework was not applied during the BE design or intervention of health services; and (iii) the influence of BE on resilient healthcare was not quantified in terms of the impacts on health outcomes and efficiency. Suggestions for future studies may include the application of the framework during the BE design or intervention of health services, using the framework to develop methods to evaluate the BE support for resilient healthcare, and creating an EBD repository to facilitate the integration and uptake of design knowledge.

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