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Lessons learnt for enhancing hospital resilience to pandemics: A qualitative analysis from Italy

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ABSTRACT

The COVID-19 pandemic has outlined the need to strengthen the resilience of healthcare systems. It has cost millions of human lives and has had indirect health impacts too. Hospital buildings have undergone extensive modifications and adaptations to ensure infection control and prevention measures, and, as it is happened following past epidemics, the COVID-19 experience might change the design of hospital buildings in the future. This paper aims to capitalise on the knowledge developed by the stakeholders directly involved with the hospital response during the pandemic to generate new evidence that will enhance resilience of hospital buildings to pandemics. The research adopted qualitative research methods, namely literature review and interviews with Italian experts including doctors and facility managers to collect data which were analysed through a thematic analysis. The findings include the identification of new needs for hospital buildings and the related actions to be taken or already performed at hospital building and service level which are viable for long term implementation and are aimed at improving hospital resilience to pandemics. The results specify how to improve resilience by means of structural modifications (e.g. placing filter zones among different wards, ensuring the presence of airborne infection isolation rooms at least in the emergency departments), technological changes (e.g. oversizing capacity such as medical gases, information technology improvement for delivering healthcare services remotely), and operational measures (e.g. assessing the risk of infection before admission, dividing acute-care from low-care assets). The needs discussed in this paper substantiate the urge to renovate the Italian healthcare infrastructures and they can be considered useful elements of knowledge for enhancing hospital resilience to pandemics in the extended and in the post-COVID-19 era.

1. Introduction

The COVID-19 pandemic is the most important global health crisis since the 1918 influenza pandemic [1]. It counts to date, globally, more than 6 million deaths, with Americas and Europe reporting most of the confirmed cases and deaths [2]. The COVID-19 pandemic has disrupted demand and provision for all healthcare services. In Italy, elective and ambulatories activities were suspended

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during the first wave of the pandemic (February–April 2020), whilst from January to September 2020 oncological screening tests decreased of about the 50% compared to the same period of 2019 [3].

The shock caused by COVID-19 has highlighted the various latent fragilities of the health system, which existed even before the start of the epidemic and the need to improve its resilience [1]. Italian hospitals are required by law[1] to implement plans to address maxi-emergencies; also at international level there are well-known references for addressing maxi-emergency at hospitals, such as the Joint Commission International standards.[2] However, the Italian healthcare system seemed not to be prepared to face the epidemic: no personal protective equipment had been previously stored, no dedicated paths and areas had been planned to people affected by infectious diseases, also the shortage of healthcare staff was a threat [4]. In particular, the pandemic has severely disrupted hospital services [5], which run out of space and resources. Therefore, the sense of urgency to redesign present facilities has increased [6,7]. The epidemiological context of the first half of 2022 is characterized by many hospitalizations of patients with COVID-19 instead of patients for COVID-19 [8]. This has been reported in the US [9] and in Italy [10], where less patients need supplemental oxygen, but many ordinary wards are still struggling to ensure safety and avoiding elective procedures delays [8]. While many questions remain about the future of the pandemic, it is evident that it will not be fully eradicated and continuous adaptations are needed [11].

Past infectious diseases have transformed our built environment because of the risk and fear of infection [12–14]. Learning from disasters is essential to guide future resilience-oriented designs [15], and in the post-pandemic era, both the construction and the built environment sector are expected to develop further a focus on resilience, occupant health, and/or safety [16–19]. Numerous settings such as urban areas [20–25], long-term care facilities [26–28], kindergartens [29], mental care facilities [30], offices [31,32], and residential buildings [33–35] have already provided suggestions for future design and spatial adaptations.

Yet, limited research has been undertaken to investigate the future of hospital buildings in the prolonged COVID-19 pandemic and in the post-COVID-19 era. All the accredited Italian healthcare structures must comply with the minimum requirements established by the Decree 94/01/1997.[3] However, the 30% of the existing healthcare assets was built more than 50 years ago and only the 1.2% after 2010,[4] suggesting that such a heritage is outdated and needs renovation. Capolongo et al. [6] have suggested a decalogue of design strategies for resilient hospitals, by means of observations made at webinars and working groups. Also, many studies proposed safety measures to reduce nosocomial transmission during the acute phase, as reported in Section 2.1. However, further efforts are needed to identify experience-based solutions viable for long term implementation, which can increase the resilience of healthcare systems. This paper aims to capitalise on the knowledge developed by the stakeholders directly involved in the hospital response to COVID-19 to generate new evidence to enhance resilience of hospital buildings to pandemics. The arising research question is: "what are the operational, structural and technological needs, emerged during the pandemic, which should be taken into account to define resilient-oriented requirements of hospital buildings in the future?".

2. COVID-19 effects on hospital buildings

2.1. Infection prevention and control measures adopted in hospital units during Covid-19

Healthcare workers (HCWs) have been at risk for being exposed to SARS-CoV-2 [36] especially in medical COVID-19 areas, including intensive care units (ICUs) [37] and Emergency Departments (EDs) [38], although rigorous infection control measures ensured rare nosocomial transmissions [38–44]. EDs resulted to be particularly affected during the pandemic as they were called to early detect and isolate potential cases of COVID-19 upon arrival [42,45–49], and to ensure patient access to care when demand exceeded available resources [50]. The main IPC measures include wearing Personal Protective Equipment (PPE) and social distance, which are considered essential in preventing human-to-human transmission of SARS-CoV-2 [51]. However, as reported by Pandey et al. [52], the pandemic has also often required conversion and adaptation of existing structures (see Table 1). In some countries community hospitals were adapted to prevent COVID-19 infection [53] or they were converted into COVID-19 centres, as occurred in Wuhan [54]. Table 1 shows that hospitals around the world adopted some common strategies, such as setting: different risk areas and pathways (e.g. clean and contaminated); dedicated COVID-19 areas; and different entrances (e.g. for staff and for patients) and areas for the immediate identification of infected patients. The COVID-19 pandemic has also accelerated the implementation of digital and information technologies for healthcare services [55–59], which has shown to have great potential in disasters management [59–61]. This technology has proved to be useful not only for outpatient care but also for inpatients, as for the Sheba Medical Centre in Israel [62]. From the above, it can be deduced that hospitals have been key infrastructures in the management of the COVID-19 crisis. They underwent extensive changes to reduce the risk of nosocomial infections and to address the surge of care demand. The COVID-19 effects on hospital buildings were significant and they regarded structural, technological, and operational aspects (e.g. spatial modifications, improved environmental hygiene, telemedicine devices, infection risk assessment).

2.2. Early suggestions for healthcare settings adaptations to face future epidemics

Designers and decision-makers should aspire for hospital designs that can accommodate ordinary and emergency operational conditions [7,74–77], thus aimed at affording flexibility [77]. Flexibility in architecture can be referred to as the ability of a building to

[1] In 2008 the so-called "Piano Emergenza Interno Massiccio Afflusso Feriti – PEIMAF" became mandatory for Italian hospitals.

[2] Further information about Standard Manuals and assessment processes are available at: https://www.jointcommissioninternational.org/standards/.

[3] The Decree is available at: https://www.gazzettaufficiale.it/eli/id/1997/02/20/097A1165/sg.

[4] The Ministry of Economy and Finance provides for data about the Italian public real estate. Data are available at: https://www.dt.mef.gov.it/it/attivita_istituzionali/patrimonio_pubblico/censimento_immobili_pubblici/open_data_immobili/.

Table 1
Summary of adopted measures for Infection Prevention and Control in hospital units based on the latest published experiences.

Examined areas	IPC measures	Sources	Country[a]
Whole COVID-19 dedicated hospital	Assessment of the infection risk for elective patients	[63,64]	USA, Italy
	Assessment of the infection risk upon arrival	[65]	China
	Isolation and segregation of suspected cases	[43,65]	USA, China
	Dedicated COVID-19 areas/units	[44,52,63,65,66]	USA, India, USA, China, Italy
	Recognizable and separated different risk areas	[52,65]	India, China
	Separated flows for suspected/confirmed cases (e.g. separated entrances, dedicated transport routes)	[52,64,67]	India, Italy, India
	Separated pathways and entrances for employees and patients	[42,52,65]	USA, India, China
	Enhancement of social distancing (e.g. improving trolleys/beds distance, reducing bed occupancy)	[40]	Germany
	PPE donning and doffing areas	[43,66]	USA, Italy
	Enhancement of cleaning and disinfection procedures	[66]	Italy
	Improved environmental hygiene (e.g. 12 air changes per hour, independent ventilation systems, exhaust air passing through HEPA filters, negative pressure rooms)	[52,67]	India, India
Emergency department	Assessment of the infection risk for elective patients	[63]	USA
	Assessment of the infection risk upon arrival	[42,46,50,68–70]	USA, Saudi Arabia, China, Singapore, Germany, Italy
	Instructional posters/marks/signals for patients/visitors/staff	[46]	Saudi Arabia
	Isolation and segregation of suspected cases	[41,43,46,67,69,70]	Singapore, USA, Saudi Arabia, India, Germany, Italy
	Dedicated COVID-19 areas/units	[41,46,49]	Singapore, Saudi Arabia, Singapore
	Outside tent as additional fever screening areas	[46,70]	Saudi Arabia, Italy
	Recognizable and separated different risk areas	[48]	China
	Separated flows for suspected/confirmed cases (e.g. separated entrances, dedicated transport routes)	[49,70]	Singapore, Italy
	Separated pathways and entrances for employees and patients	[71]	Singapore
	Increase of beds number	[41]	Singapore
	Enhancement of social distancing (e.g. improving trolleys/beds distance, reducing bed occupancy)	[45,49]	China, Singapore
	Reducing droplets spread (e.g. using partitions, temporary cubicles).	[70]	Italy
	PPE donning and doffing areas	[41]	Singapore
	Improved environmental hygiene (e.g. 12 air changes per hour, independent ventilation systems, exhaust air passing through HEPA filters, negative pressure rooms)	[46,48]	Saudi Arabia, China
Radiography and radiology suite	Isolation and segregation of suspected cases	[41,71]	Singapore, Singapore
	Dedicated COVID-19 areas/units	[70]	Italy
	Recognizable and separated different risk areas	[41,66,71]	Singapore, Italy, Singapore
	Separated pathways and entrances for employees and patients	[71]	Singapore
	PPE donning and doffing areas	[66]	Italy
	Improved environmental hygiene (e.g. 12 air changes per hour, independent ventilation systems, exhaust air passing through HEPA filters, negative pressure rooms)	[41,71]	Singapore, Singapore
General ward	Dedicated COVID-19 areas/units	[72,73]	China, Canada
	Recognizable and separated different risk areas	[72,73]	China, Canada
	Separated pathways and entrances for employees and patients	[72]	China
	PPE donning and doffing areas	[72,73]	China, Canada
	Enhancement of cleaning and disinfection procedures	[72,73]	China, Canada
	Improved environmental hygiene (e.g. 12 air changes per hour, independent ventilation systems, exhaust air passing through HEPA filters, negative pressure rooms)	[63,72]	USA, China
	Self-closing doors equipped with hands-free foot-operated openers.	[72]	China
Intensive care unit	Dedicated COVID-19 areas/units	[68]	Singapore
	Recognizable and separated different risk areas	[66]	Italy
	Increase of beds number	[68]	Singapore
	PPE donning and doffing areas	[66,68]	Italy, Singapore
	Enhancement of cleaning and disinfection procedures	[68]	Singapore
	Improved environmental hygiene (e.g. 12 air changes per hour, independent ventilation systems, exhaust air passing through HEPA filters, negative pressure rooms)	[63,68]	USA, Singapore
Endoscopy department	Instructional posters/marks/signals for patients/visitors/staff	[74]	Italy
	Recognizable and separated different risk areas		
	Separated flows for suspected/confirmed cases (e.g. separated entrances, dedicated transport routes)		
	Separated pathways and entrances for employees and patients		
	PPE donning and doffing areas		
Community hospital	Assessment of the infection risk upon arrival	[53]	Taiwan
	Dedicated COVID-19 areas/units		

[a] The column refers to the Country in which the discussed hospital unit is placed. The Countries are reported per each reference, accordingly.

adapt to changed spatial and functional demands according to short, medium or long-time perspectives [78]. Flexibility can mean modularity [79] and adaptability [80]. It supports coping with technological and epidemiological changes; thus, it is a fundamental requirement to consider in the hospital design process [7]. Specific practical considerations for hospital buildings to reduce infectious diseases transmission through built environment adaptations can be found in Dietz et al. [77]. According to these authors [77], Heating Ventilation and Air Conditioning (HVAC) systems play an increasingly important role in this sense. Thermal space conditioning should be separated from ventilation provisions. Mechanically delivering air through the facade would permit all patient rooms to be operated in isolation, and individually adjusted to be positively or negatively pressurized, depending on patient requirements, with a higher degree of operational resilience. It should be considered to add anterooms as they serve as additional buffer between common areas and protected spaces to prevent pathogen spread and provide a location for hospital staff to apply and remove personal protection equipment. However, they occupy floor area and increase the visual barrier between patient and rounding care team, therefore, increase costs. Also, future designs should reconsider the best way to triage and complete initial assessment of patients who present symptoms related to airborne viruses to minimize exposure to areas with other patient types if possible (ibid).

3. Materials and methods

This research adopted a set of qualitative research methods for data collection and analysis. These include a literature review presented in Section 2, semi-structured interviews with experts and thematic analysis to analyse the recorded interviews. Expert interviews are frequently employed as instrument for the collection of data [81], as they can serve to establish an initial orientation in a field that is either substantively new or poorly defined. Experts are seen as guides who possess certain valid pieces of knowledge and information which are not available to the researcher [82].

Table 2
Information about participants and organisations involved in the study.

ID	Profession	Role in the hospital/ organisation	Type of organisation	N° of hospitals managed by the organisation	Catchment area (n° of inhabitants)[a]	N° of hospital beds[b]	Region
P1	Doctor	Gastroenterology Unit Coordinator	Local Health Authority	12	1.081.380	1425	Campania
P2	Doctor	Head of the General Medicine Department	Local Health Authority	3	540.376	746	Lombardy
P3	Architect	Head of the Technical Department	Local Health Authority	4	230.000	568	Lombardy
P4	Engineer	Head of the Prevention and Protection Service	Polyclinic University Hospital	1	1.012.602	1097	Lazio
P5	Doctor	Digestive Endoscopy Unit doctor	Polyclinic University Hospital	1	1.012.602	1423	Lazio
P6	Engineer	Engineer at the Prevention and Protection Service	Local Health Authority	12	1.081.380	1425	Campania
P7	Doctor	Intensive Care Unit Coordinator	Local Health Authority	12	1.081.380	1425	Campania
P8	Doctor	Emergency Department Coordinator	Polyclinic University Hospital	1	1.012.602	1423	Lazio
P9	Architect	Head of the Prevention and Protection Service	Hospital Authority	3	962.890	705	Campania
P10	Doctor	Doctor at General Medicine Unit	Polyclinic University Hospital	1	1.012.602	1423	Lazio
P11	Doctor	COVID-19 Coordinator	Local Health Authority	12	1.081.380	1425	Campania
P12	Safety expert	Head of the Prevention and Protection Service	Local Health Authority	5	250.000	242	Lombardy
P13	Doctor	Emergency Department Coordinator	Local Health Authority	3	3.469.156	973	Lombardy
P14	Engineer	Head of the Technical Department	Local Health Authority	6	1.012.602	675	Lazio
P15	Architect	Head of the Prevention and Protection Service	Polyclinic University Hospital	1	1.012.602	1423	Lazio

[a] The catchment area refers to the Local Health Authority in which also Hospital Authorities and University Polyclinic Hospitals are located, as reported by the database of the National Health System provided by the Minister of Health (available at: https://www.salute.gov.it/portale/documentazione/p6_2_8_1_1.jsp?id=6&lingua=italiano).
[b] Hospital beds do not include day-hospital and day-surgery.

Thematic analysis is a qualitative research method used for identifying, analysing and reporting patterns found within a data set [83]. The approach used by the authors is exploratory, or "content-driven", rather than confirmatory. Exploratory analyses are commonly used to generate hypotheses for further studies or to build theoretical models derived from the data [84]. Previous qualitative studies which combine semi-structured interviews and thematic analysis proved to be efficient in identifying stakeholder views on little known research areas [85,86]. This section provides details on participants recruitment, data collection and analysis.

3.1. Participants

Eighty-four potential participants were selected based on their expertise. The sample included Italian clinicians and hospital facility managers, including engineers and architects, directly involved in the hospital response to COVID-19. The Italian National Health System is regionally based, and healthcare services are mainly provided by Local Health Authorities and Hospital Authorities which manage different hospitals on a certain territory. In particular, Local Health Authorities oversee organising and providing both hospital and community services. Participants were selected for being HCWs at Hospital Authorities and Local Health Authorities located in the three Italian regions, i.e. Lombardy, Lazio and Campania. These regions were selected as representative respectively of the situation in the North, Centre and South of the Country. All participants were invited by email to join the study and to participate in online recorded interviews. A cover letter was sent to each of them along with a participant information sheet, to explain the interview aims, their role in it and how the data would have been used and that participant consent forms would have been recorded as separate file before the interview.

Out of 84 HCWs contacted, 15 agreed to participate, including eight doctors and seven facility managers, of which five were from the prevention department and two were from the technical department. Eight participants were from medical departments. Five interviewees were from the Campania region and from two different organisations; six interviewees were from the Lazio region and from three different organisations; four interviewees were from the Lombardy region and from three different organisations. Most of the interviewees hold a leading position within their organisations, as heads and coordinators of entire departments or hospital units. Table 2 provides for a summary of participants' roles and organisations.

3.2. Data collection

Individual online semi-structured interviews were carried out and recorded using Microsoft Teams. The adopted language was Italian (as it was the native language of both interviewees and the interviewer). The interviews had a twofold purpose: (a) understanding the pandemic effects on hospital buildings and the strategies adopted to cope with the pandemic at building levels; (b) exploring possible functional, structural, and technological features to improve resilience to future pandemics. The study required two interview guides, one for the clinicians and one for the facility managers. The reason behind this choice was that clinicians could share their experiences and thoughts regarding one Department/Unit, while engineers and architects could provide a general overview of the entire hospital and better insight on engineering and architectural adaptations. The questions regarded: (i) the type of organisation, the type of Unit/Department which the participants belonged to and their role in it; (ii) adopted safety measures and services modifications due to the COVID-19; (iii) considerations on lasting hospital changes in terms of both services and infrastructures. The interviews were of about 20 min duration and were carried out between April 24th, 2021 and July 13th, 2021. All interviews were anonymised and transcribed verbatim, using at first Microsoft Teams and then correcting them by listening to the audio recordings. Ethics procedures of the University of Salerno was followed.

3.3. Data analysis

The analysis of interviews was undertaken using thematic analysis and the step-by step guide by Braun and colleagues [83,87] was used. First, the researcher read the entire data set to familiarise with the data, making notes of the identified patterns. Second, the researcher divided the text into meaning units and attached labels as a first attempt of generating codes. Refinement of codes led to the definition of themes and sub-themes, generated in an inductive manner. Theme captures something important about the data in relation to the research's question and represents some level of patterned response or meaning within the data set [80]. All the collated extracts of each theme were read to check if they formed a coherent pattern. Lastly, research team meetings were held to review transcripts and validate themes. The analysis required a constant moving back and forward between the entire dataset in order to check and adjust codes and themes. To perform the data analysis tables were created in Microsoft Excel and conceptual maps to organize codes, sub-themes and themes were developed. The data analysis was entirely performed in Italian, the results were translated in English for publication.

4. Results

The interview aimed at understanding the pandemic induced hospital building adaptations and at shedding light on future hospital needs. The data analysis led the authors to identify six sub-themes, grouped into three main themes which are: "Adopted strategies to dismiss"; "Adopted strategies to keep in the future"; "Strategies to plan" (Fig. 1). Participants were grouped into three clusters, namely facility managers (FM) which includes maintenance and health and safety managers as well as a COVID emergency coordinator; general medicine doctors (GMD) who comprise internal medicine and digestive disease clinicians; emergency medicine doctors (EMD) who comprise emergency department and intensive care unit coordinators. Table 3 briefly describes each identified code by illustrative quotes, themes and sub-themes are grouped by domain summary, which are "Strategies to cope with COVID-19 at hospital service level" and "Strategies to cope with COVID-19 at hospital building level".

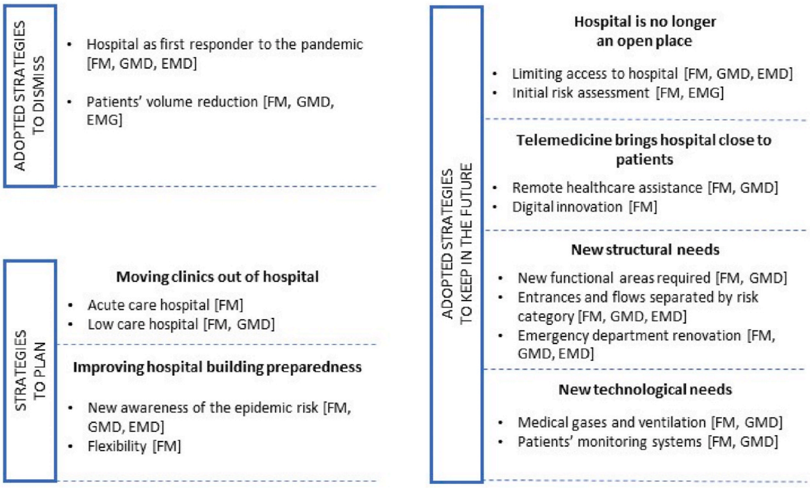

Fig. 1. Graphical abstract of themes, sub-themes and codes with additional information about the type of participants who contributed to the identification of the topic.

4.1. Adopted strategies to dismiss

In Italy, during the first wave of COVID-19 (February–April 2020) elective activities were suspended as it was necessary to cope with a suddenly increased number of COVID-19 patients. Hospitals were at the frontline in the fight against the virus, as community surveillance and home care were unavailable. Since the second wave (October–December 2020) the situation has changed as different types of patients accessed to hospital care and surveillance systems became more efficient at the community level. At the same time, following ministerial guidelines, the number of intensive care beds was increased, by mainly converting existing wards. A shared approach consisted into having a limited number of structures entirely dedicated to COVID-19 patients to leave other hospital "*clean from Covid-19*". Elective procedures were allocated with large period of time range to avoid overcrowded environments and to perform sanitization and cleaning procedures (e.g. in endoscopy theatres). This led to a drastic reduction in the number of patients treated, with consequences (in terms of oncological disease rebound) which are still unknown to date. The adopted strategies, of reducing the patients' volume and suspending elective activities, were due to the initial unexpected wave but they have been already dismissed or they are going to be dismissed soon.

4.2. Adopted strategies to keep in the future

4.2.1. Hospital is no longer an open place

Limiting and filtering access to hospital wards for both day-care users and inpatients (e.g. those who needed surgical procedures) has proven to be an extremely efficient safety measure. Hospitals have been equipped to check the risk of infection upon arrival (by means of COVID-19 test) and, except for patients with special needs (i.e. children and non-autonomous), cares and relatives have been kept outside hospital settings to reduce crowding and to improve social distance. This risk reduction procedure it is thought to be long-lasting, in this sense the hospital is no longer a free-access place (this procedure is still in place in Italy in 2022 indeed). From a technical point of view, this approach has led to a reorganisation of entrances and pathways inside the hospital, in some cases differentiated for patients, staff and contractors. "*A badge has been provided to all the hospital employees in order to control the access to some hospital settings (…). Contractors and patients use separated entrances which have been equipped with filter zones*" (P12).

4.2.2. Telemedicine get hospital close to patients

The interviewees shared the perception that telemedicine and remote consultation had a boost due to the pandemic and they can improve healthcare services even in the future. During the first wave, remote consultation reduced the number of people admitted to hospitals. At the same time, it is expected that telemedicine can support communities placed in disadvantaged locations (e.g. rural areas) in accessing healthcare services. There is the need for a better information sharing between hospital and general practitioners to enhance the synergism between different level of care and related structures. Information technologies can also improve the collaboration between community hospitals, in-home care and acute care hospitals. Moreover, some of the facility managers argued that the digitalisation and dematerialization of information and data are changing both medical and administrative activities and settings. Home working will lead to desk sharing and thus to costs containment in technical and administrative departments.

4.2.3. New structural needs

The pandemic required new functional areas, above all the donning and doffing areas, filter zones and testing (for COVID-19) rooms. In some cases, dedicated areas for outpatients and day-hospital activities were created ex-novo, requiring new pathways and the conversion of existing hospital areas. Following the ministerial guidelines, intensive and sub-intensive care beds were increased in number. To do so, entire hospitals were converted into COVID-19 dedicated hubs, and they were equipped with filter zones, in order to have different risk areas. Flows and environments were reorganized according to the novel perception that the

Table 3
Summary of data analysis results.

Domain summary	Themes	Sub-themes	Codes	Illustrative quote(s)
Strategies to cope with the COVID-19 at hospital service level	Adopted strategies to dismiss	–	Hospital as first responder to the pandemic	"During the dramatic period of the first wave all activities were converted into COVID-19 sphere in a very short time" (GMD – P2). "The pandemic has overturned the activities of my Health Authority since February 2020 (…). For some period, all ordinary procedures were suspended, and non-COVID-19 units were grouped into limited portions of existing assets, while the remaining parts were converted into COVID-19 areas" (FM - P3). "The hospital has been the first responder to the pandemic while it is not meant to be so (…) with the consequence collapse of Emergency Departments while good results could have been achieved at home. Something should be revised at the community level more than at the hospital level as the prevention is mostly made by community services" (FM - P6). "We suddenly turned to COVID-19 unit from internal medicine, and we have been so for a year" (GMD – P10). "The pandemic had hugely impacted hospital activities, (…) structures and plants to address the healthcare demand required from the territory" (FM - P15).
			Patients' volume reduction	"The pandemic influenced the hospital activities in terms of patients volume reduction and selection. Exams were scheduled with a wide time range not to overcrowd waiting areas" (GMD – P1). "This global reduction of hospital services we can provide (…) is leading to a decreased number of inpatients (…) with unknown consequences. In this regard it has been said that the next pandemic will be the cancer" (GMD - P5). "In the last months we have experienced an overcrowding of Emergency Departments as ambulatories activities were kept suspended for a long time" (EMD – P8).
	Adopted strategies to keep in the future	Hospital is no longer an open place	Limiting access to hospital	"The accesses to hospital wards have been strictly regulated with established procedures which were communicated to the personnel" (FM – P3). "Limiting access to common areas has been an effective measure. We discovered that potential points of contagion (…) were the environments of apparent calm" (EMD - P13). "Limiting as much as possible the access of carers turned out to be an effective (prevention) measure" (FM - P15).
			Initial risk assessment	"The most effective measure (for risk reduction) has been the selection of patients before admission. All the patients who require an invasive procedure as endoscopy are screened and this has led to new flows and environments to create a triage for accessing the hospital" (GMD - P1). "This organisation of controlling and screening accesses (before admission) will be long lasting" (GMG – P5). "The less effective measure has been the temperature body checking at entrances" (EMG – P15).
		Telemedicine brings hospital close to patients	Remote healthcare assistance	"(Among the long-lasting measures) there will be for sure the opportunity of interacting with patients remotely. Sharing documents with general practitioners encourages teleconsulting" (GMD - P1). "I strongly believe that telemedicine can support remote areas. Moreover, hospitals and community services can be effectively connected and become a net only by a supporting information technology" (GMD - P2). "If we increase the use of technology, a home-based hospitalization is no longer impossible to achieve, especially for low care needs, even with the tools we already have at our disposal" (FM - P3). "We can see the future of hospitals through the lens of remote healthcare assistance so that a patient can ask for care without physically going to hospital, this makes easier and faster the first consultation" (FM – P15).
			Digital innovation	

(*continued on next page*)

Table 3 (*continued*)

Domain summary	Themes	Sub-themes	Codes	Illustrative quote(s)
				"The pandemic has led to (…) an organisational revolution based on the digitization and dematerialization of documents and information (…). The need for social distancing has encouraged home working which implied a reduction of occupied desks within the hospital settings and, therefore, a reduction of operational costs. All these processes are evolving fast, and they will profoundly change technical and administrative activities" (FM - P15).
	Strategies to plan	Moving clinics out of hospital	Acute-care hospital	"Community services should be improved leaving to hospitals their proper vocations of urgencies" (FM - P14). "We should relocate these (community) activities not to concentrate everything inside the hospital. This is the future, (…) it can be a good way (…) to concentrate specialistic and urgency activities at hospitals" (FM – P15).
			Low-care hospital	"The half part of what we do can be performed on an outpatient basis (…), many diagnostic services could be easily relocated on a community level" (GMD - P5). "Community services, which are now absent, must be enhanced, otherwise people continue to flock to the emergency department, that, well, breaks out" (GMD - P10).
Strategies to cope with the COVID-19 at hospital building level	Adopted strategies to keep in the future	New structural needs	New functional areas required	"The reorganisation of my hospital deliveries required that outpatients could not access my unit and there was the need to identify new environments for them outside the unit itself. The same occurred for sedated patients waiting for being discharged, who occupied the rooms originally dedicated to day-hospital" (GMD - P1). "The first adaptation intervention regarded the creation of donning and doffing environments" (FM - P3). "Some hospitals have arranged in very short time interdivisional isolation rooms, placed close to the ED, where patients can wait for COVID-19 tests response, then if they result to be positive, they are transferred to dedicated COVID-19 hubs, otherwise they are transferred in ordinary wards" (FM - P6). "We placed partitions within the COVID-19 ward corridors to have at least one clean "area", to be used by contractors, as the food service, so that a designed ward operator could take from there the trunks inside" (FM - P12).
			Entrances and flows separated by risk category	"The reorganisation of flows, entrances and environments is linked to a new culture which considers the hospital as a system regardless of the specific unit of destination to limit the risk of infection" (GMD - P1). "In the near future there will be pathways for identified COVID-19 patients and pathways at low risk of infection. These flows start from the ED and continue in red zones, at high risk, and green zones, at lower risk" (GMD - P2). "I think that the strategy to separate flows within the hospital should remain in the future. The hospital should be organised in a way that infections patients can follow a certain and dedicated pathway, as it happened for infectious disease wards" (EMD - P7).
			Emergency department renovation	"The ED should be always structured in a way that infectious patients could be received, isolated and treated there. Once you establish this structural modification then you can differentiate pathways (…) at least within the ED you should always have an isolation room and a dedicated pathway for suspected infectious patients" (EMD - P7). "Infectious and non-infectious pathways will not be merged again as this is a protection system regardless of COVID" (EMD - P8). "The ED lost its feature of transit place and became an area of treatment and care. Starting from the pre-Triage, the first point of COVID-19 risk assessment, everything has been duplicated as for the Triage, clinics, waiting and recovery rooms. From a structural point of view the ED duplicated its square meters. Even the trunks for cleaning and disinfection were differentiated. So, it was like having two EDs, with some points of connection" (EMD - P13).

(*continued on next page*)

Table 3 (*continued*)

Domain summary	Themes	Sub-themes	Codes	Illustrative quote(s)
		New technological needs	Medical gases and ventilation	"The pandemic made it clear that air conditioning systems and ventilation systems are two important requirements, which have been underestimated in the past (…) many hospitals were unprovided" (GMD – P1) "We know that air conditioning and ventilation systems are not required by law in general wards and even where these systems exist (…) they do not provide for sufficient air changes, especially when patients are under oxygen therapy (…) (FM - P3). "We needed to triplicate the oxygen supply in some cases, so we understood the need to self-produce oxygen in the future, rather than storing it" (FM - P3). "We needed to intervene on the oxygen distribution system" (FM – P4). "ICU beds have been placed in ordinary wards so integrative medical gases systems were installed" (FM – P15).
			Patients' monitoring systems	"We should allow information technologies to enter more profoundly into our built environment. You can imagine that on one hand a single room solves the problem of social distancing and isolation but on the other hand how can we control each patient? This requires a big effort in terms of human resources. This effort can be tolerable if clinicians and nurses are equipped with widespread monitoring systems. Monitoring systems include surveillance cameras and vital parameter monitors. (…) Patients monitoring systems should not be reserved to intensive care units (…) but they should be diffused" (FM - P3). "A key adaptation has been the installation of monitors and cameras inside the patient rooms (…) so that we could monitoring how equipment were function from outside" (GMD – P10).
	Strategies to plan	Improving hospital building preparedness	New awareness of the epidemic risk	"All the structural and technological changes should be followed by an increased number of human resources. There is a balance between involved personnel and the number and type of criticalities we can face" (GMD - P2). "During this dramatic circumstance the hospital building accreditation and construction regulation turned to be outdated and not able to create environments adequate to COVID-19 alike events" (FM – P3). "The impact of the pandemic has changed the healthcare staff behaviour which is now more hygiene-oriented in terms of clean/dirty flows, PPE usage (…). Such a personal training will unlikely get lost" (FM - P4). "Due to the unknown development of the epidemic, what I think will last is the usage of PPE (…) and the increased attention to the protection of HCWs" (GMD – P5). "In the aftermath of the COVID-19 experience we will not be caught unprepared. We are now more prepared to face a future epidemic if it will occur (…) but our infrastructures should be able to contain the risk of contagion even of one single person so not to spread the pathogen to others" (FM – P9). "One thing is changed for sure: we understood it (an epidemic) can happen. Our mental habitus will remain altered" (FM – P14). "The pandemic plan is a document to be periodically prepared and tested" (FM – P15).
			Flexibility	"During the dramatic circumstance we have faced, it emerged that the (Italian) regulation of hospital requirements must be revised. There are technological and structural aspects to rethink. There is the need for infrastructures so flexible that they can be adjusted according to the epidemiological context immediately. To do so we need bigger floor to ceiling height, additional technical voids and a flexible architectural layout above all at the entrances (…). I think, at this point, that a modern hospital which learned from the pandemic can only have single bedrooms, and I know it is difficult, the Italian

(*continued on next page*)

Table 3 (*continued*)

Domain summary	Themes	Sub-themes	Codes	Illustrative quote(s)
				hospital portfolio should be entirely revised in this sense" (FM - P3). "In designing a future ward, I would put dedicated filter areas, even if they are not required by law (…). In a general medicine unit, I would have never treated an infectious patient, right? But now we have gained the idea that it can occur (…). Thus, hospital infrastructures must become more flexible, accessible, and adjustable (…). I need to be able to convert a general medicine unit into ICU designing the medical gases system for emergency, in other words oversizing it for ordinary activities" (FM - P4). "Nowadays all new projects must be infectious disease-oriented, as an infective patient can reach any specialised unit (…). This means that we need a minimum amount of isolation rooms which can be linked to other services by dedicated pathways." (FM - P9). "We are continuously monitoring the occupancy rate of our COVID-19 dedicated facilities so that if it exceeds the 70% we provide to dedicate other units to COVID-19 elsewhere. This modularity allows us to address also the care demand of non-COVID-19 patients (…). In case of an outbreak the availability of a prepared infrastructure is essential, and the preparedness is about separating pathways" (FM - P11). "If I was in charge of designing a new hospital, I would do something completely different from current references, I would concern (…) creating independent units as much as possible, similarly to the detached blocks hospital type "(FM - P14).

hospital constitutes a complex of interconnected components especially when it comes to reduce nosocomial infections. The pandemic affected the functional and structural organisation of Eds and their links with the rest of the hospitals. Specific COVID-19 routes were identified in hospitals buildings, from the EDs to specialised units, and they are perceived as a long-lasting protection measure even regardless of COVID-19. The pandemic required the introduction of temporary single recovery rooms, where patients could wait for COVID-19 test response. "*It should be considered that the patients who are accessing the hospital are of three types: there are recognised COVID-19 patients, likely COVID-19 patients and recognised non-COVID-19 patients. As the majority of them falls within the second group, single and temporary isolation rooms are needed*" (P3). Areas for pre-Triage were placed in order to identify positive cases in a timely manner. In some cases, there was a duplication of EDs environments and a doubling of square meters. Diagnostic imaging areas, as the CT scan rooms, were duplicated in most EDs, providing more flexibility. In general, the need for differentiated pathways and environments, for infectious and non-infectious patients, in every hospital's EDs is considered a new achievement which will last in the future.

4.2.4. New technological needs

Technological interventions were required to convert general wards, operating theatres and other existing units into ICUs. Medical gases plants, especially oxygen supply systems, were incremented or installed if absent. Interviewees suggested that mechanical ventilation systems should be revised and implemented in all medical settings, as the Italian accreditation laws do not require them in general wards to date. Monitoring systems have been installed to check upon infectious inpatients, including surveillance cameras, so that HCWs were not forced to enter each room to perform control activities. A diffuse wiring and Wi-Fi network is perceived as a necessary technological improvement for a better data and information sharing among professionals, at both hospitals and community level.

4.3. Strategies to plan

4.3.1. Improving hospital building preparedness

Flexibility is the key characteristic of a modern hospital according to several interviewees and it can be achieved by providing more single rooms, higher floor to ceiling height (to allocate suspended ceilings and technical installations), additional technical vertical voids and a flexible architectural layout which support the rapid response in case of an outbreak. Flexible architectural layout considers the opportunity of reaching each point with separate flows (at least by two pathways) and in separating entrances. Future design projects are likely to consider filter areas and donning and doffing areas in each hospital ward, as well as a minimum number of airborne isolation infection rooms even where infected patients are not supposed to be hosted. Flexibility can be reached also by organisational strategies, such as monitoring the occupancy rate of COVID-19 wards and ensuring modularity and scalability in increasing available beds number. The opportunity of dividing hospital areas should be always considered, and it requires technological (e.g. independent air conditioning and ventilation systems, diffuse medical gases system), organisational (e.g. more personnel, risk assessment procedures) and structural (e.g. isolation rooms or filters) means.

The pandemic not only has changed hospital environments but also HCWs behaviours who have gained a new hygiene culture and a new collaborative approach. Indeed, the epidemic risk is perceived as a definitive risk which require adequate design and physical infrastructures. The pandemic risk should be always considered in risk management procedures so to start preventive and monitoring activities, as outlined pandemic plans were missing or ignored at the beginning of 2020, "*while not only they should be updated but also simulated periodically to check if the chains of communication work and if the warehouse stocks are enough. I hope this is something metabolised at the strategical level, as it is bad to be caught unprepared*" (P15).

4.3.2. Moving clinics out of hospital

Both doctors and facility managers argued for the opportunity of moving low-care activities outside the hospital. Community care can be improved by means of additional infrastructures and additional home-care services. In this way emergency, acute care and post-acute care will remain at hospital while ensuring the continuity of healthcare assistance. As observed, this could also lead to a reduction of hospital beds (P14). In any case, medical clinics should be separated from the proper hospital wards. "*I would create structures dedicated to elective patients. This means increasing community healthcare infrastructures leaving to hospitals their proper nature of urgency and acute care places, otherwise, during a future epidemic, emergency department will get clogged again and elective procedures will be suspended (…). I agree with the National Plan for Recovery and Resilience*[5] *to move towards "proximity home" and "community hospitals" to relocate healthcare deliveries and to treat by day surgery and day hospital the vast majority of Italian pathologies*" (P14).

5. Discussion

This study comes to identify key lessons in terms of emerged and emerging operational, structural, and technological needs, summarised in Fig. 2, which will likely affect future hospital building design and renovation interventions. The listed needs are particularly relevant during the current transitional phase of the pandemic, which requires safety measures to be in place to manage the increasing number of infected patients who are hospitalised for non-COVID-related ailments. The results of this paper enhance the understanding of faced criticalities and related responses to cope with COVID-19 at hospitals, thus they propose experience-based suggestions about actions to be taken to increase hospital resilience to future pandemics and to better handle the current transitional phase. Fig. 3 depicts the existing correlations between measures to be taken at hospital service and building level to cope with COVID-19 and future alike crisis. In addition, the identified and analysed needs can serve as a reliable source of knowledge in a future revision process of hospital requirements. The results are in line with the existing literature on design strategies for resilient hospital facilities [6], providing new experience-based insights and evidence to substantiate those strategies. Also, the findings of this paper further support previous studies [7,77] that flexibility is a key characteristic of hospitals resilient to pandemics. It is worth noting that the term "flexibility" acquires different meanings in accordance with the interviewer background. For doctors it means scaling up the COVID-19 dedicated beds number through the conversion of existing ordinary wards, but also ensuring the availability of differentiated structures and pathways. Flexibility in this case has been referred to as "modularity", while in the reviewed literature the term "modularity" was referred to modular and fast construction used to improve hospital capacity bed space. Architects and engineers link flexibility to constructive and typological characteristics of the built environment. In this sense, it can be implemented in terms of adaptability (e.g. converting an ordinary ward into intensive care unit) and availability (e.g handling an infected patient in ordinary wards or EDs, separating entrances, etc.). As outlined by the existing literature the concepts of flexibility, modularity, availability, adaptability are not univocally defined, however flexibility can imply minor changes, affordable in short-term, while adaptable buildings can require major interventions to satisfy emerging needs [80]. The lessons learnt for the enhancement of hospital building resilience to pandemics are further detailed in the following sections.

5.1. Knowledge advancements

Doctors and facility managers opinions resulted to be mutually complementary, proving not only that the role played by the built environment in increasing hospital resilience is consistent but also that the two types of stakeholders should contribute equally to designing future interventions.

Italy appeared to be particularly fragile in terms of continuity of community services. The COVID-19 experience has led to the conclusion that there is the need for separated infrastructures dedicated respectively to low-care and acute-care services (see Section 4.3.2). There is now the chance of improving proximity networks, infrastructures and telemedicine thanks to the Plan for the National Resilience and Recovery which invests 7 billion euros into improving the community services before 2026. Digital and information technologies will gain attention even during non-emergency periods: remote assistance can support screening and patients' follow-ups (e.g. by phone calls) and inpatients can be checked by means of video camera and vital parameters monitoring systems (see Section 4.2.4).

All the adopted strategies at the hospital building level (see Table 3) concurred to the effective response to the pandemic, and they constitute a set of newly acquired knowledge, which can drive the design and the management of hospital buildings in the future. The collected data are in line with the international experiences reported in Table 1, in addition they suggest a set of actions to be taken (see Figs. 2 and 3) which can be a useful knowledge reference in the prolonged pandemic. The paper's results allowed a better overview of the hospital functionality by referring to the wider healthcare network which hospitals are located into and thanks to the panel of interviewed experts involved in the management of the pandemic at both hospital and community level. It must be reminded that

[5] The National Recovery and Resilience Plan is part of the Next Generation EU (NGEU) programme, namely the € 750 billion package that the European Union negotiated in response to the pandemic crisis (https://www.mef.gov.it/en/focus/The-National-Recovery-and-Resilience-Plan-NRRP/).

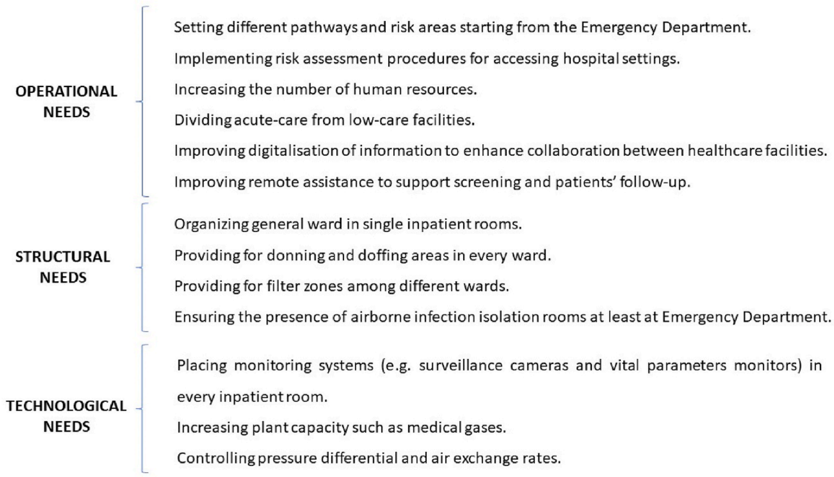

Fig. 2. Structural, operational, and technological needs emerged during the COVID-19 pandemic which can help driving the design of new hospitals and the renovation of the existing infrastructures.

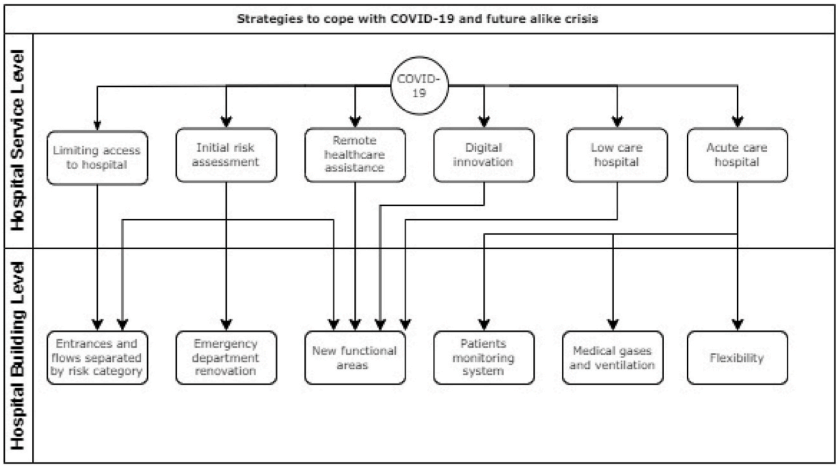

Fig. 3. Correlations between operational and physical adaptation strategies to cope with COVID-19 and future alike crisis.

hospitals are elements of the healthcare systems, thus the emerged needs should help designing infrastructures which are rapid in implementing the organisational response required by the contingent scenario, while not all the infrastructures must face the worst scenario concurrently. Hospitals have different roles within the healthcare organisation thus emergency and ordinary activities are planned in accordance with the role played by each facility. Finally, those experts argued for a review of the Italian hospital accreditation requirements.

5.2. Practical implications for built environment adaptation

The hospital needs reported in Fig. 2 have been recognised as significant lesson learnt which suggest adaptations viable for long term implementation. In this matter, a recurrent topic among the interviews has been the need of flexibility-oriented design, as for general wards to be quickly converted into ICU if needed. This means ensuring the presence of air conditioning and ventilation systems, oversizing medical gases capacity for ordinary activites. This is in line with what suggested by Dietz et al. [77], who argues for a separation of thermal conditioning from ventilation systems too. Moreover, a newly acquired belief is that every hospital should be designed having in mind the risk of epidemics, which is linked to creating redundancy in the hospital system (e.g. placing filter zones, donning and doffing areas, airborne infection isolation rooms). This is particularly topical in the current epidemiological context, which does not imply shaping every hospital as an infectiouss disease centre, but it still requires architectural adaptations and organisational measures, as an infected patient can reach every specialised ward.

Several strategies adopted at the hospital service level resulted to have positive impacts on hospital services delivery, thus they will be kept in the future. Indeed, there was a clear convergence of views on the need of limiting, filtering and dividing accesses to hospital, even by means of physical adaptations. For example, the patients' screening before hospitalization and the control of the public access to hospital wards and settings will last. In this scenario, the built environment needs to change too in order to accommodate these novel functional needs, for example providing triage rooms at hospital halls as well as differentiated entrances for staff and patients (Fig. 3).

The analysed experiences have taught that a resilient model of ED must contain at least one airborne infection isolation room, and it requires enough square meters to duplicate its functionality during epidemics (see Section 4.2.3). In this sense, the Italian portfolio of EDs should be retrofitted, as airborne infection isolation rooms are not required by law in every ED.

The interviewees stressed that hospital resilience is based upon the concurrence of different strategies, mutually connected as they foster each other. For example, it has been argued that single rooms ensure social distance and infection control but they require the adaptation of technological equipment (e.g. patients monitoring systems). This solution is also linked to the opportunity of reducing hospital bed number in the view of treating elective patients at community facilities. It is worth noting that having only single rooms may increase costs and it could not be practical nor useful in case of other mass casualty events.

6. Conclusion

The COVID-19 outbreak has had a major impact on societies, as well as built environments, worldwide. In Italy, during the first wave, the majority of existing hospitals were suddenly dedicated to COVID-19 patients, at the expense of other needs. An increasing body of literature illustrates how individual hospitals and units reengineered their environments and reorganized their services during the acute phase of the pandemic. Few research investigated the consequences of the COVID-19 pandemic on hospital building design and functionality in the future. In the prolonged pandemic (i.e. transitional phase) many patients are hospitalised with COVID-19 rather than for COVID-19, meaning that built environment adaptations and safety measures are still required. Starting from the knowledge developed by the stakeholders directly involved in the pandemic in hospital settings, this paper generates new evidence that will enhance pandemic resilience of hospital buildings by identifying emerging needs and suggesting the related strategies which are viable for long term implementation. The authors have analysed what has been done during the acute phase of the pandemic, and how hospitals are managing the pandemic transitional phase and which future perspectives can be derived from the healthcare workers experience. This research revealed that the adaptation process experienced during the pandemic is linked to a novel behavioural and infrastructural preparedness which will likely last in the future. In addition, the contribution to the field of hospital building resilience relies on the identification of novel operational, structural, and technological hospital building needs. The results are not limited to a specific building or unit, but they cover the wider range of healthcare services considering that the enhancement of hospital resilience can be achieved even in relation to community services arrangement. Considering that the Italian hospital building portfolio is dated the findings might help hospital managers and Local Health Authorities in rehabilitating and renovating existing structures and in planning for the future. It has been observed that the Italian accreditation law for hospitals should be revised to make these critical infrastructures more resilient to pandemics. The findings of this paper reflect the point of view of a group of Italian experts, thus they can not be generalised to the entire Italian hospital portfolio. However, the needs outlined (Fig. 2) can be considered as useful elements for the definition of new requirements for hospital buildings in the future. The technical and economic feasibility of the interventions suggested by this paper must be further explored, and it will be discussed in future developments of this research. In this sense, the opinions of policy makers and stakeholders external to hospital settings will be collected as well. It must be considered also that the lesson learnt presented in this paper derive from the direct experiences of hospital personnel which are conditioned by the organisational and logistic constraints and not only by the physical environment they worked into. A possible future development of this research regards the opportunity to examine the potentialities of the physical environment in terms of adaptability and flexibility so to know how to implement prompt and effective response in case of an outbreak. In this sense, the set of novel hospital building needs reported in this paper can also extend, update, and detail the existing assessment tools of hospital safety and preparedness. Existing frameworks can be enhanced for designing new hospitals or to evaluate the existing infrastructures which might need renovation interventions to be more resilient to pandemics.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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