Towards a resilient hospital design

Emerging design considerations for future healthcare facilities after the pandemic COVID-19.

Colophon

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Preface

This research represents a one-year master's thesis as part of the Design and Construction management chair of the MSc program track Management in the Built Environment. The analysis and findings are intended to provide recommendations for future hospital design and build towards more resilient healthcare facilities.

COVID-19 pandemic was becoming one of the most challenging situations of the last years in history. The crisis demanded the construction of entire new hospitals and the transformation of non-healthcare buildings into emergency facilities. I was attracted to the topic and strived to contribute to the current situation with my investigation.

Although the research development was simultaneous with the outbreak and hospitals were dealing with multiple challenges. Many real estate and facility managers participated and contributed information in different ways.

Acknowledgements

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Manuela Pretelt, June 2021

Abstract

Background: COVID-19 has highlighted the importance of the healthcare systems in society. The pandemic overwhelmed hospitals and forced rapid and radical changes in healthcare organizations' working practices and management structures (MASS Design Group, 2020; Ramboll, 2021; Capolongo et al., 2020). The virus led to unfamiliar environments, new spatial configurations of hospitals were necessary to cope with the surge capacity, new protocols and strategies were fundamental to respond to the crisis. Past pandemics have occurred, and other infectious diseases and viruses might come. COVID-19 is not going to be the last challenging situation for the health sector. Thus, healthcare systems could become more resilient. Hospitals need to resist future outbreaks, maintaining and adapting critical functions during crises (Ramboll, 2021). It is essential to learn from the experience of the COVID-19 pandemic to be more prepared for future events.

Aim: This practice-based research aims to gain insight into the pandemic experience by investigating how hospitals dealt with the different phases of the virus in practice. The intention is to understand the consequences of the hospital design outbreak and provide recommendations to futureproof projects to a virus-like COVID-19.

Research questions: 1. What is the relationship between the spatial characteristics of existing hospitals in the Netherlands and the safety measures taken by them during the different phases of the COVID-19 pandemic? 2. Based on the pandemic experience, what interventions should be considered in hospitals to future-proof projects to virus-like covid-19?

Methodology: First, through a general questionnaire, information on building adaptations and working practices of hospitals in the Netherlands during the pandemic was assessed. Then follow-up in-depth interviews with chosen facility and real estate managers that answered the survey would be conducted to reflect on the crisis period and understand the decisions and choices taken regarding planning, design, and engineering during the different waves in the country's hospitals.

Findings: The pandemic in the Netherlands increased cohesion and collaboration between healthcare organizations. The national government advised the coordination of the emergency response, and the decisions within each organization were driven by independent Crisis Management Teams (CMT). Clear guidance facilitated the decision-making process of the measures and services that needed to be implemented. In general, hospitals felt well prepared for the pandemic. The rate in preparedness increased over time, so after the building, technical and employee-focused modifications, hospitals took more control of the virus and responded to the surging demand for covid-care.

Additionally, an analysis considering three spatial characteristics of hospitals: type, building year, and urban density was done to determine a distinction in the measures taken. It was found that the spatial characteristics studied in this research differentiate the safety measures taken by hospitals over the three waves of the pandemic. Findings suggest that academic hospitals offered more services for staff, like free parking and child care, than general hospitals. Furthermore, generic hospitals did more building and technical interventions to provide additional capacity since the academic type was the last resort for covid care. Findings also suggest that hospitals built before 2010 might have an excess capacity, whereas hospitals constructed after 2010 are more compact buildings. Technical modifications were seen in both older and new buildings. Also, the information from the survey suggests that hospitals located in more low urban areas are less busy but might need more different employee-focused measures like shopping services than hospitals located in high urban areas.

Moreover, one of the main lessons from the research is that staff is a core asset for hospitals. The well-being of workers is connected to the quality of care. Thus, the healthcare system is heavily dependent on patient-related employees and, therefore, the resiliency of the overall organization. The investigation also provides six recommendations for future hospital developments that seek to increase flexibility, robustness, and adaptive capacity of healthcare design. The experience of the pandemic added impetus to the existing requirements; it helped identify coming trends and build up towards future-proof facilities to a virus-like COVID-19.

Limitations of the research: This graduation thesis was done during the second and third wave of the COVID-19 pandemic. The collection of the data was challenging. Healthcare professionals were busy with the crisis to help with the completion of the survey and the interviews. The survey was expected to be distributed when hospital admissions were decreasing; nevertheless, hospitalizations were high during a prolonged time, limiting the survey's response rate. Due to the available time and data collected, a statistical analysis was not developed, and the findings were based only on a qualitative evaluation. Qualitative research is subject to bias due to the interpretation of the information collected.

Practical implications: This research increases knowledge about the consequences of the COVID-19 pandemic and provides recommendations for renovations and new hospital developments to be more prepared for a future virus-like COVID-19 and build towards more resilient healthcare facilities.

Scientific relevance: From a scientific and professional standpoint, this investigation is relevant since little research has been done concerning the future of hospital design, specifically regarding design solutions influenced based on the experience of COVID-19 first, second and third wave. The investigation contributes to more flexible, robust and adaptable facilities to respond to a possible future crisis like COVID-19.

Originality/ value: Limited literature is available on the implications of COVID-19 for future hospital design. This investigation increases knowledge in the field of hospital design and the consequences of the COVID-19 pandemic in the Netherlands.

Key Words: Future hospital design, COVID-19 pandemic response, Hospital characteristics, Building interventions, Technical interventions, Employee-focused measures, Adaptability, Flexibility, Robustness, Healthcare resilience.

1. Introduction

SARS-CoV-2, also known as COVID-19, is a contagious respiratory disease that first appeared in China in 2019; the transmission of the virus primarily occurs person-to-person via drip contact (coughing). The virus can remain infectious in the air for several hours and cover large distances (1.5m); furthermore, it can stay on surfaces for 2-3 days (World Health Organization, 2020). Other similar infectious diseases such as SARS-CoV and MERS-CoV have affected humans in the past. However, COVID-19 is a strain non identified before, and due to the rapid spread, it was declared a pandemic on March 11th, 2020. Fourteen months later, the infections surpassed one hundred fifty-two million cases worldwide (World Health Organization, 2020). The pandemic has an enormous impact on countries worldwide regarding health systems, lifestyle, social interactions, economic activities, government policies, and financial markets (WHO Regional Office for Europe, 2020).

Managing COVID-19 has been a challenge for healthcare institutions, and this research paper investigates the consequences for future hospital design due to the COVID-19 outbreak. For this, a detailed analysis of the situation in hospitals in the Netherlands is made. First, the current overview of hospital admissions is explained, followed by describing the responses regarding spatial adaptations made in Dutch hospitals during the different phases of COVID-19. Furthermore, the relevance of the research is presented together with the concept of resiliency.

Reading guide

This report consists of the graduation research divided into six main chapters. The first part introduces the pandemic situation in hospitals in the Netherlands. Then, the spatial modifications and adaptations made in the facilities during the different phases of COVID-19 are described.

Chapter 2 provides background information about hospital typology development, Dutch healthcare context and main elements of hospital architecture. The factors that have influenced the changes in hospital design are explained to gain knowledge about hospital physical configuration and understand the challenges of hospital design over time.

Chapter 3 describes the design of the explorative practice-based study that will be carried out in the investigation. Furthermore, the research methods and analysis techniques to collect and analyze the data will be explained.

Chapter 4 analyses the findings from the survey and the interviews. Charter 5 presents the conclusion, discussion, and recommendations of the research. Chapter 6 displays a reflection about the topic and process of the investigation.

1.1 Current situation

The 1st COVID-19 patient in the Netherlands was confirmed on February 27th of 2020. Cases started increasing rapidly, especially in the provinces of Noord-Brabant and Limburg (van Heel, 2021). The National Institute of Public Health and Environment (RIVM) coordinated the crisis response in collaboration with the regional public health organization (GGD), the National Outbreak Management Team (N-OMT) and the COVID Readiness Team (CRT), among others. In the beginning, the country was not prepared to quantify how many people were affected by the virus by a lack of test capacity. However, weekly testing rates have been increasing since the pandemic started, the numbers of positive cases are not accurate. Not all residents who presented symptoms received treatment and were not registered in the national data (National Institute for Public Health and Environment, 2020). Thus, the numbers considered in this overview are the hospitalization rates reported in 73 Dutch hospitals by the National Intensive Care Evaluation Foundation.

Until June 22 2021, there have been registered 69,432 patients treated in nursing wards which correspond to 81.7% of the total hospital admissions (National Intensive Care Evaluatie, 2020). As figure 1 shows, the first peak of workload in-patient care was reached in March with 556 new patients per day. Since then, hospital admission decreased closely to 0 patients in July. The second wave started in mid-July; numbers increased again, reaching 430 new hospitalized patients per day in December 2020. The third wave overlapped with the second wave in February 2021. After a long period of surging demand and strict government restrictions from December 2021 to March 2021. Currently, hospitalizations are decreasing.

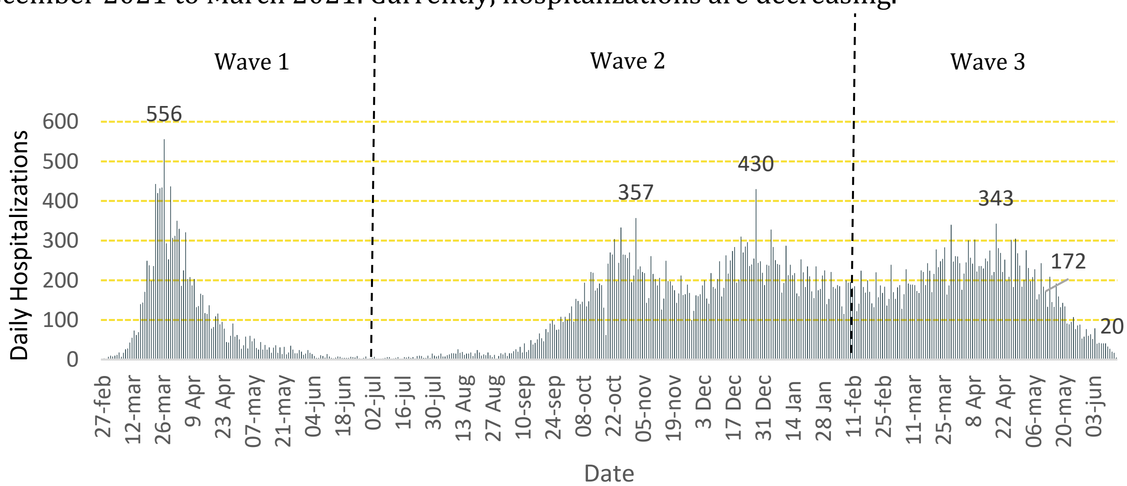

Figure 1. Coronavirus (COVID-19) hospitalized patients in the Netherlands 2020 Source: (National Institute for Public Health and the Environment, 2020)

Another reliable estimate that must be considered to understand COVID-19 behavior is the reproduction number (R), representing how fast the virus is spreading. The number shows how many people on average are infected by one patient diagnosed with COVID-19. At the beginning of the pandemic, during February and March, the virus spread faster; R was around 2.17, in June 2021, R is 0.75. Currently, hospitalizations have decreased significantly, and the virus is spreading at a lower rate (Rijksoverheid, 2020). The decline in the spreading of the virus is a consequence of government measures and vaccinations. About 13.8 million vaccinations have been applied. The government is slowly implementing relaxation measures to protect as much as possible the vulnerable groups and guarantee quality care for all patients, trying to prevent the hospital staff from becoming overwhelmed again (Government of the Netherlands, 2020).

Hospital admissions differed significantly by age during the first, second and third wave. Figure 2 shows the distribution by a group of patients in nursing wards with suspected or proven COVID-19. Hospitalizations are mainly occurring in patients between 45 to 80 years old. Deaths are primarily occurring in patients between 60 to 80 years. Therefore, it can be said that the elderly is the most affected group (Nationale Intensive Care Evaluatie, 2020).

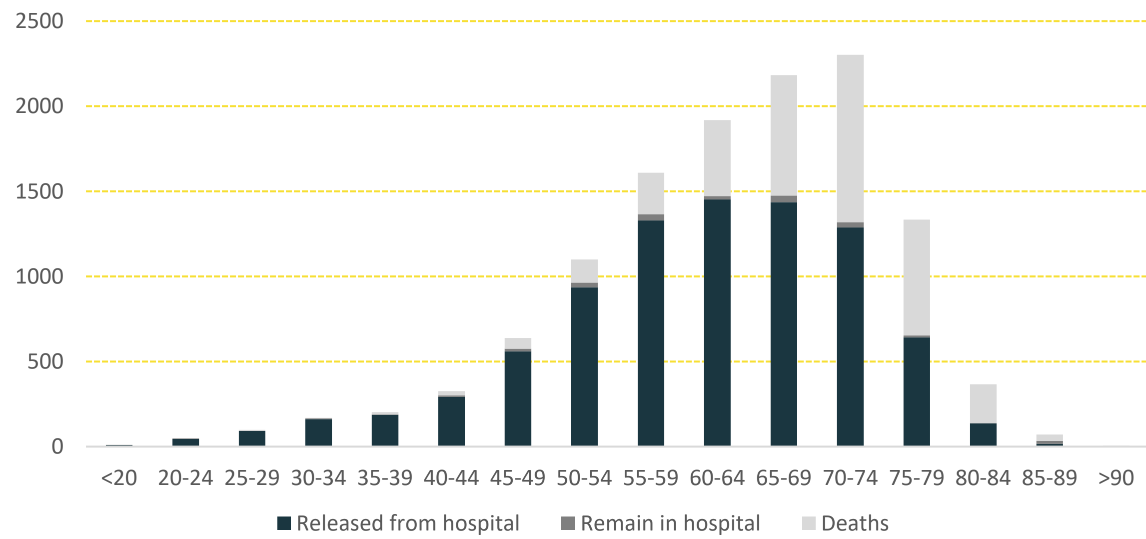

Figure 2. Age distribution of patients with suspected or proven COVID-19 status in the nursing wards Source: (Nationale Intensive Care Evaluatie, 2020)

Analyzing more in-depth hospital numbers, the total number of patients registered in Intensive Care Units (ICU) due to COVID-19 until June 22nd, 2021, is 12,702, corresponding to 18.3% of hospital admissions for this disease. As figure 3 depicts, at the height of the first wave there were admitted 126 new patients in intensive care daily. From late March to August, the beds required by COVID 19 patients progressively declined. Since August, numbers started rising again; in December, the daily number of patients reached 64 new cases per day, and after slightly decreasing, numbers came 69 new ICU admissions on April 5th. The occupied beds have fallen to 41 new entries per day (Nationale Intensive Care Evaluatie, 2020).

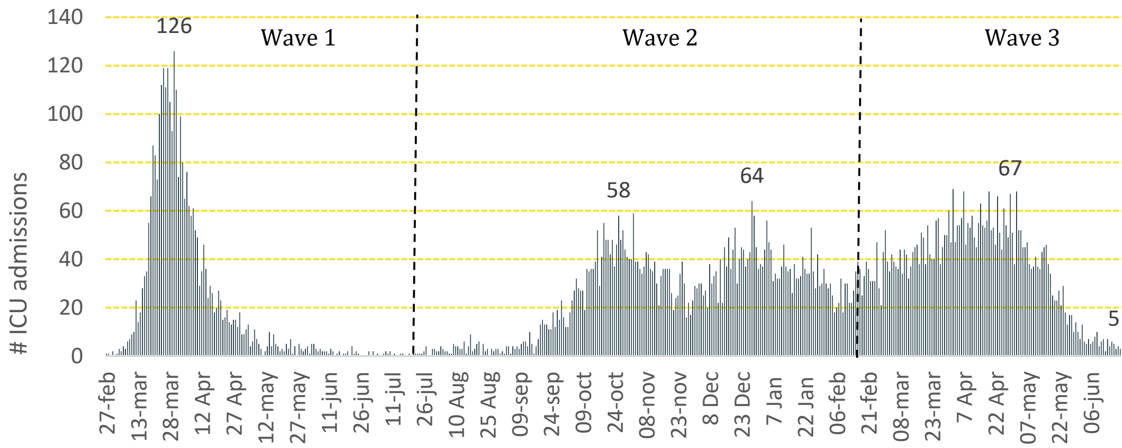

Figure 3. Coronavirus new daily intensive care patients in the Netherlands March to November 2020, Source: (Nationale Intensive Care Evaluatie, 2020)

To better comprehend the situation of Intensive Care Units in Dutch hospitals, the accumulated number of patients in ICU per day should be analyzed. Figure 4 gives an overview of the total amount of patients present in the ICU per day. During the first wave peak, the demand for beds (1306) surpassed the supply of ICU beds in Dutch hospitals. In the Netherlands, typically, there are 1150 ICU beds available, with an occupancy rate, of 70%. With the corona outbreak, there was a need to scale up from 1700 to 2500 beds in April 2020 for Covid patients and other persons that might required ICU care (WHO Regional Office for Europe; European Commision Directorate; European Observatory on Health Systems and Policies, 2020).

A difference between the first and the other waves was that more patients could be treated in the nursing wards than in the ICU since patients received oxygen when hospitalized in nursing wards. According to the Dutch association of Internists, the ratio of ICU/ward changed since the beginning of the pandemic. During the first wave, the ratio was about 1 to 2. During September, the ratio changed to 1 to 4, meaning there were 4 COVID-19 patients in the general wards and one in ICU (Nederlandse internisten Vereniging, 2020).

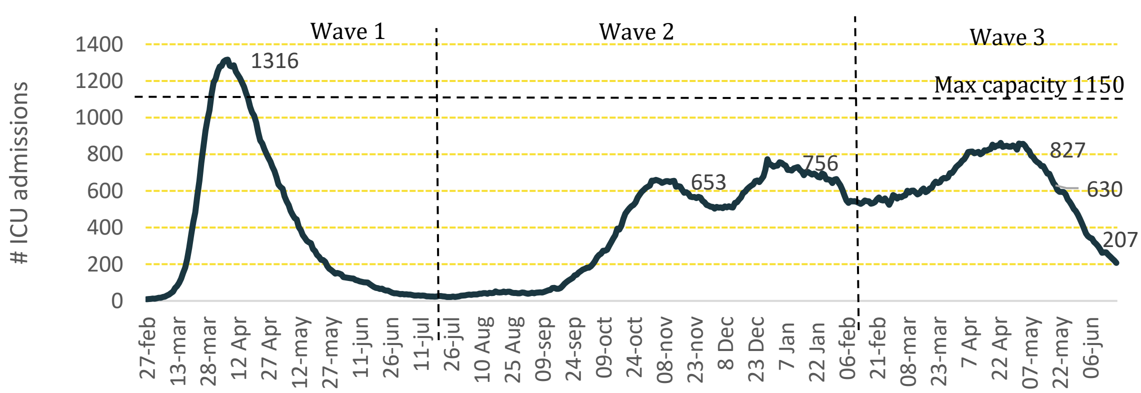

Figure 4. Coronavirus total number of patients with suspected or proven COVID-19 present in the ICU per day Source: (Nationale Intensive Care Evaluatie, 2020)

Moreover, the length of stay in ICU also differed over time. Between March and April 2020, the mean was 20.5 days, while in May – June 2021, the average time was reduced by almost half to

12.8 days. The reduction might be because medical treatments and knowledge about the virus have improved, as well as that there is suggestive evidence that the average age of COVID-19 patients has dropped. Those people are at lower risk of being taken into the ICU. Although the situation seemed to improve over time, the reality is that the healthcare system was under high pressure, partly because of the prolonged period and a decreasing sense of urgency to adhere to guidelines than at the beginning (National Intensive Care Evaluatie, 2020a).

During this 1st stage of the pandemic, there was an acute situation; the emergency required rapid and radical changes in hospitals' management structures and working practice (Ramboll, 2021). There were huge uncertainties about pathology and the duration of the virus; regular care treatments had to be postponed; there was a lack of testing capability, and the capacity margins from acute care were exploited. However, depending on local organizational and technical conditions, the lack of ICUs could be solved by scaling up the system to the required intensive care units (Ramboll, 2021). Additionally, the shortage of medical staff, present before the pandemic, was possible to overcome during the extra demand period. Some former nurses were willing to assist COVID-19 patients for a limited period.

On the other hand, the 2nd and 3rd wave of the virus has been more chronic. Although medical treatment has improved, the staff is exhausted from the hospital's lengthened demanding situation; employees are exposed to additional demands like increasing working hours, adopting new responsibilities, and working practices. The working force is already experiencing problems of stress, depression, and poor mental health. Elective care had to scale up again, and currently, there are not enough qualified personnel to help in the nursing wards anymore (Ramboll, 2021).

1.2 What measures were taken in hospitals in the Netherlands

Measures of isolation, quarantine, and physical distancing were taken in the country during the multiple waves of COVID-19 to lower the risk of transmission. In hospitals, additional spatial measures and adjustments were made to support the changes in logistics and operations caused by the surging demand for COVID-19 care (Capolongo, et al., 2020). This chapter is focused on the adaptations made to the existing hospitals to respond to the new pandemic requirements. The impact was felt across the medical departments, especially in emergency and acute and respiratory care; the interventions can be classified in the three categories explained below.

Building interventions

As a response to the pandemic, some general spatial adaptations were made in Dutch hospitals to minimize the transmission risk of the virus inside the facilities and cope with the surging demand for COVID-19 care. Primarily, visual cues were installed together with the provision of hand-alcohol near the entrances to designate functional use of spaces and reinforce safety protocols for patients and staff like physical distance (1,5m), maximum occupancy of the building and disabled furniture in waiting areas, among others (Mass design group + Adridne Labs, 2020; van Heel, Erasmus Medical Center Visit, 2020; Ramboll, 2021).

Additionally, internal traffic routes were modified to separate infected (red stream) and non-infected patients (green stream) inside the building. Signs and special demarcations on floors were installed to help differentiate the new routes. In some hospitals, dedicated entrances for staff were enabled. Additional plug-in spaces were arranged in the parking areas with triage services for testing and assessing patients' symptoms. (Mass design group + Adridne Labs, 2020; Bologna, Setola, Marzi, Naldi, & Vittoria, 2020; Ramboll, 2021; Ramboll, 2021).

During the early phases of the pandemic, the critical areas such as the emergency department and the ICUs became quickly overloaded and were considered potentially infected departments. Some hospitals opted to separate the essential departments into infected and non-infected wards to have smaller and safer independent areas for regular and COVID-19 care. Furthermore, to increase capacity in some hospitals, the refurbishment and repurpose of departments into COVID-19 wards and ICUs occurred. Physical interventions like installing Perspex barriers between patients and staff desks or opening windows in in-patient rooms to enhance visual communication between staff and patients were made (Mass design group + Adridne Labs, 2020; van Heel, Erasmus Medical Center Visit, 2020; Carthey, 2021).

Technical adaptations

As a complement to the building adaptations made to scale up and cope with the surging demand, technical interventions were essential to make the space suitable for COVID-19 care. In some cases, changes in the ventilation system, Installation of air pressure barriers, and HEPA filters were necessary to provide adequate infrastructure for COVID-19 care (ARUP, HKS, 2021). Moreover, installing communication systems for monitoring patients during isolation and extra communication accessories for staff was also required, together with additional medical equipment and ventilators (van Heel, 2020). An example of some of the interventions mentioned before can be explicitly seen in the Erasmus Medical Center of Rotterdam. The cardiac and pulmonary department were adapted into temporary ICUs during September 2020 to prepare for the second wave of the virus. Figures 7,8 and 9 show the transformation process in a ward not in use.

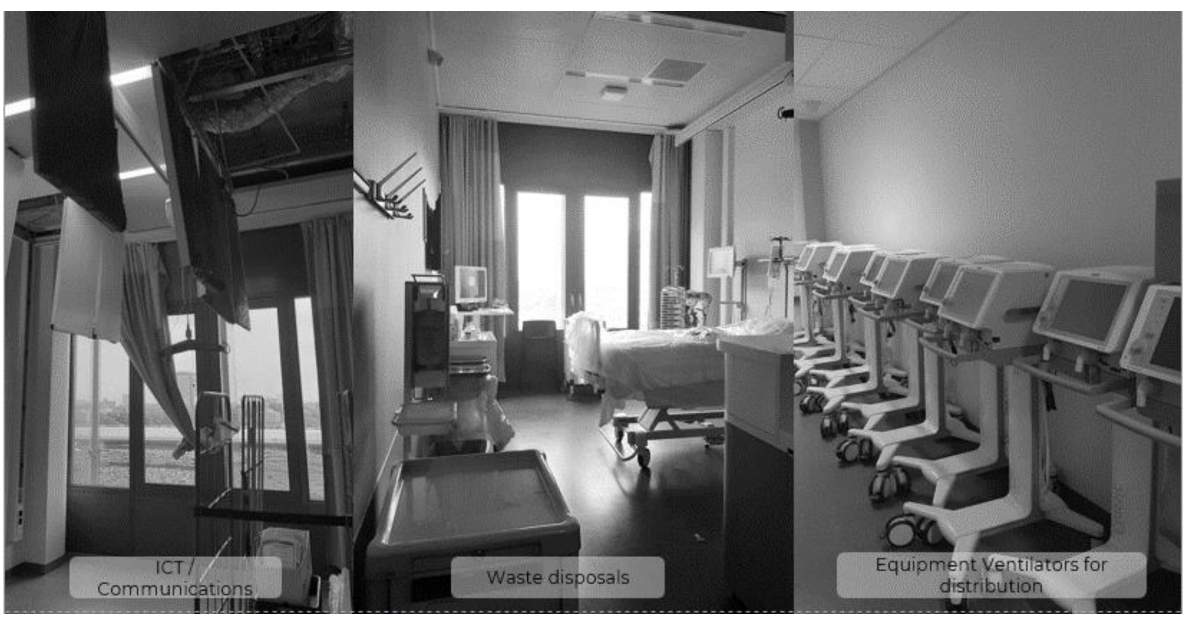

Figure 7. Adaptation of single-patient rooms into COVID-19 ICUs in Erasmus Medical Center, Source Own picture.

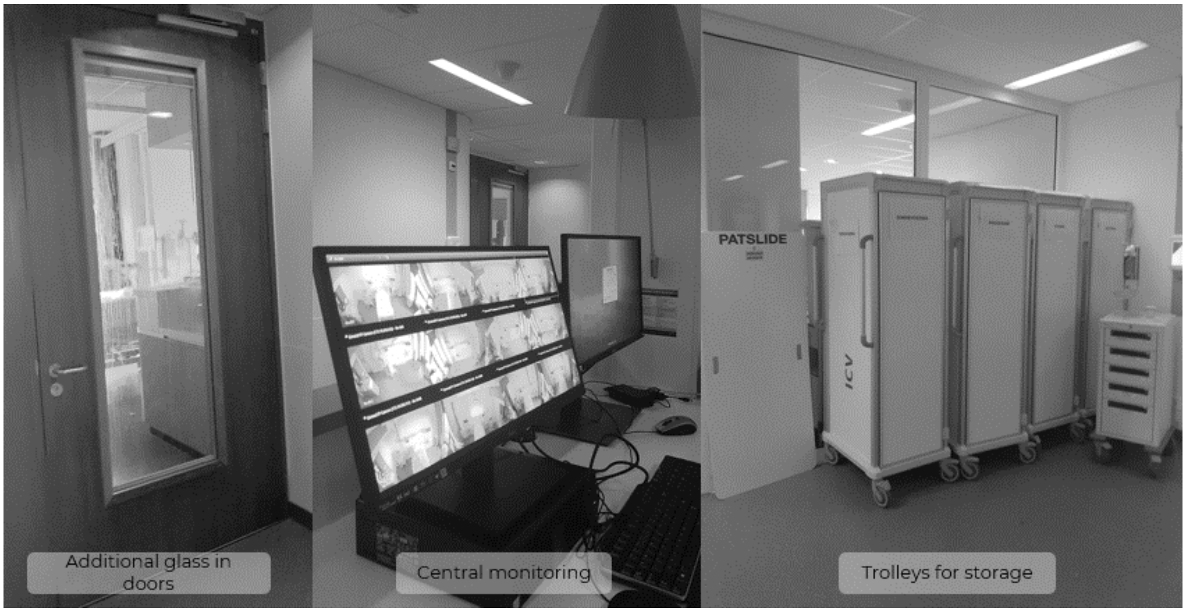

Figure 8. Adaptation of single-patient rooms into COVID-19 ICUs in Erasmus Medical Center, Source Own picture.

Figure 9. Adaptation of single-patient rooms into COVID-19ICUs in Erasmus Medical Center, Source Own picture.

In addition to the interventions mentioned above, online consultation became an alternative to support the delivery of regular care, especially during the second wave of the pandemic. E-health reduces hospital visitors while outpatient care is still being delivered during the pandemic (REHVA Federation of European Heating, 2020).

Services for staff

Hospitals adopted services to support their healthcare workers during the outbreak to cope with increased workload and strengthen safety measures and protocols inside facilities. Some examples are additional break rooms, extra attention for mental well-being, childcare services, free parking, supplementary shopping services, and temporary accommodation in local hotels for employees (ARUP, HKS, 2021; van Heel, 2020). The previously mentioned services might cause changes in the physical configuration of healthcare facilities requiring additional space or reconfiguration of the existing building.

1.3 Resilience

COVID-19 is not going to be the last virus that the healthcare sector needs to handle. Past pandemics and viruses have left many victims. During 1918 -1920, one-third of the population got infected with Influenza. The pandemic left 50 million deaths worldwide. Later, the Hong Kong SARS caused between 1 and 3 million fatalities worldwide in 1968 during 2002 – 2003; SARS left 8,437 sick people, including victims. In 2009, the Swine flu had affected 214 countries; there were 60.8 million cases and between 123,000 and 203,000 deaths. From January 2020 until May 2021, have been 160.813.869 confirmed cases and 3,339.002 victims of COVID-19 worldwide. The increasing trend of confirmed cases and victims is uncertain, although vaccination already started (World Health Organization, 2020).

COVID-19 care response overwhelmed the healthcare system of many European countries, including the Netherlands. The staff and space were pushed to their limits, the capacity problems have been magnified because of the unavailability of sufficient supplies of protective equipment (Gupta strategies, 2020). Furthermore, due to the quick overload of ICU and isolation rooms in most Dutch hospitals and the lack of scale-up during the first wave, a perceived need to adapt non-patient areas such as convention centers and concert halls in regular in-patient wards (Ramboll, 2021). Additionally, some patients were transferred from the Netherlands to Germany to cope with the surging demand during the different waves.

Leaning from the pandemic experience could contribute to building more resilient healthcare systems and being more prepared for future viruses and crises like COVID-19. According to Ramboll, 2021 the concept of resilience could be understood as "*the capability to maintain and adapt critical functions when faced with changes*". Resiliency should be met across all the four thematic fields of Ramboll's framework shown in figure 10. The four aspects of resilience are briefly described below:

Staff: Health care workers are a crucial resource in the overall system. Healthcare organizations are dependent on their human capital, and the quality of their work is influenced by their well-being (Ramboll, 2021).

Systems: Represents the organizational level with the different stakeholders involved in their roles and responsibilities. The aim is to integrate different models of care such as health centers, outpatient clinics, hospital clinics and rehabilitation centers, among others. (Ramboll, 2021).

Space: Planning and design of hospitals involve a variety of actors and complex technological requirements. Facilities should provide a healing environment for patients and adapt to future changes (Ramboll, 2021).

Supply chain: Coordination and regulation of supplies to support medical operations of healthcare facilities are key management strategies to ensure the correct functioning of the system (Ramboll, 2021).

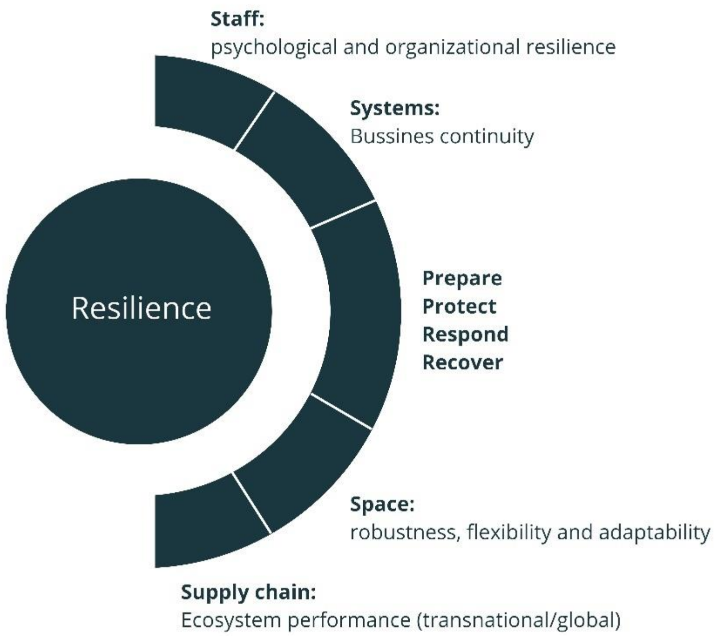

Figure 10. Resilience framework

This report focuses on the category of space and investigates how to be better prepared for a future pandemic from hospital design. The research is based on the changes and measures taken in Dutch hospitals during the different phases of the COVID-19 virus. Thus, the study investigates how hospitals dealt with the pandemic and study the essential measures in future-proof hospital design to a virus-like COVID-19.

02
Background

2. Background

2.1 Hospital design history and typology development

The design of hospitals has made a dynamic transformation through history. Around the years, 800 AC healthcare institutions arose, churches and hospitals were closely linked, and hospitals were charitable institutions for helping the sick and the poor (Wagenaar et al., 2018). With the development of cities in the 13th Century, non-religious forms of healthcare started appearing; one of the first hospitals is the Ospedale Maggiore in Florence and is an example of renaissance architecture. During this era, contagious diseases emerged. Cities combatted the virus by building barracks for the sick people outside the built areas or isolating them to prevent the spread of the diseases. Moreover, during the renaissance, the human body was first studied, medical research started, and teaching hospitals were developed to understand human anatomy and educate students in this field (Wagenaar et al., 2018).

During the beginning of the 18th Century, hospitals continued being charity places, especially in German-speaking countries; civilian hospitals were mainly focused on taking the poor out of the streets and preventing people from becoming ill. Nevertheless, during this century, epidemics like cholera affected cities, death rates were very high since no medical treatments to cure patients, and hospital infections were tremendous. From the mid-18th Century, with the industrial revolution and the development of the sewage system by John Snow in London, hygiene conditions of cities improved significantly (Tulchinsky, 2018). Hospital design principles were related to the disposal of natural ventilation in all the spaces. Thus the typology of corridor hospitals appeared, and later on, the building typology of pavilion emerged, technology was used to improve the disposal of fresh air in possible infected spaces (Wagenaar et al., 2018).

Most hospitals built in Europe in the 19th Century adopted the pavilion system, which allowed patients' wards to receive natural light and constant fresh air flow in most spaces. This typology was recommended by the committee of the Academie des Sciences as an ideal layout which provided advantages like the flexibility to gradually expand the capacity of the building by adding more pavilions next to each other, as is shown in figure 6 (Wagenaar et al., 2018).

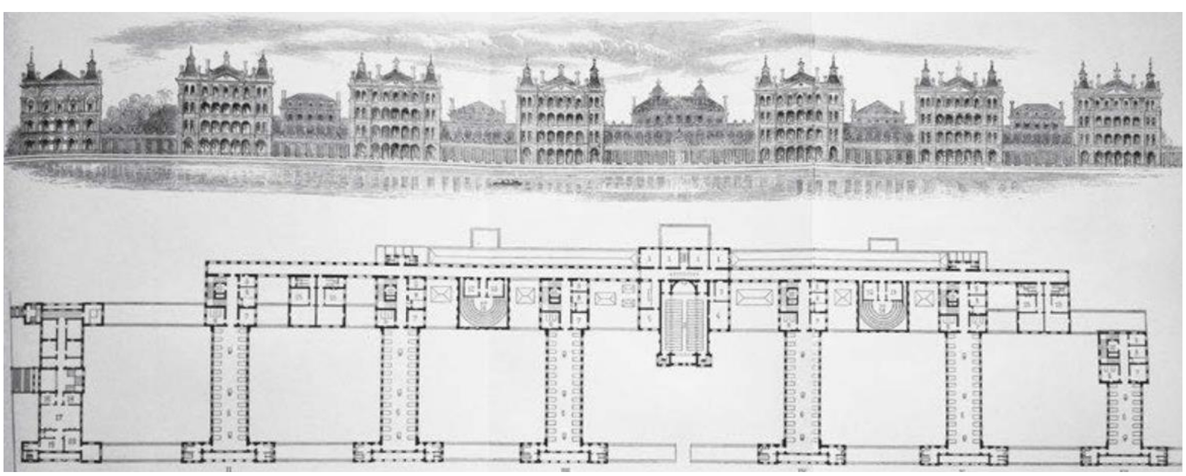

Figure 6. St. Thomas hospital, London, UK 1866-1871. Multistoried pavilions, Source: (Wagenaar et al., 2018)

The industrial revolution brought economic growth and technological developments, contributing to public health improvements (Szreter, 2004). In 1942 anesthetics and bacteria were discovered, and patients could be treated for epidemics and other health issues. With the emergence of surgery procedures, the operating theatre became one of the first functional units found in hospitals. Subsequently, due to continuous technological development, the pavilion typology evolved into more compact hospital layouts (Wagenaar et al., 2018).

Furthermore, in Europe, large health medical centers also emerged, combining apartment buildings with different health functions such as medical school, laboratories, clinic, and nursing home for the elderly. Although these projects were large and involved a mix of operations, they also offered logistical advantages due to the separation of internal traffic flows in the different wings of the building that spread from a central core (Wagenaar et al., 2018).

After the second world war, the demand for hospitals increased in Europe. Buildings needed to be expanded without creating logistical chaos internally; thus, typologies like T-type, H-type, and K-type arose. An example of an H-shaped hospital in Basel, Switzerland, can be seen in figure 8. The "alphabet" types were characterized by the distinction of functions such as in-patient wards and outpatient department in the different wings of the building. In the Julianaziekenhuis in Terneuzen, in the Netherlands, shown in figure 9, the H composition clearly distinguished the central medical departments such as in-patient wards and outpatient diagnosis. The separation of wings provided flexibility facilitating the future expansion of the hospitals if necessary (Wagenaar et al., 2018).

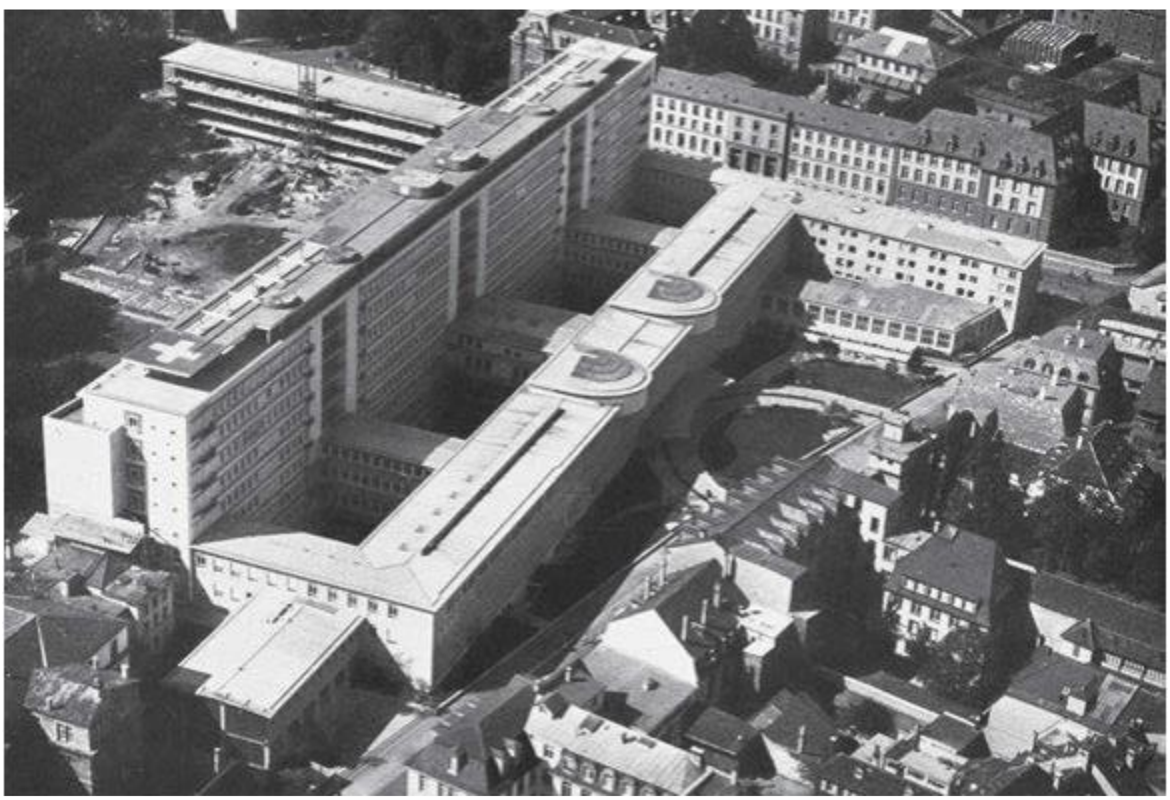

Figure 8. Burgerspital, Basel, Switzerland, 1937-1946. H-shape hospital, Source: (Wagenaar et al., 2018)

Figure 9, Julianaziekenhuis, Terneuzen, the Netherlands, 1954, H-type hospital, Source: (Wagenaar et al., 2018)

From the mid of 1955s, the "wide foot" model or matchbox appeared together with the emergence of the maternity department and intensive care units on account of technological innovations. Hence the design of spaces had to be adapted to facilitate the accommodation of new technical equipment. The typology consisted of a high-rise building containing patient wards on top of a low-rise building holding the other functions. Nevertheless, the expectation that outpatient departments rapidly expanded and in-patient wards reduced the adoption of low-rise typologies again (Wagenaar et al., 2018).

Between 1981 and 1985, the Amsterdam Medical Center (AMC) is shown in figure 10. was finished. In this project, architects created a spatial combination between permanent medical departments and semi-public areas, introducing the atria as one of the main spaces for the entrance of the buildings due to technological innovations (Wagenaar et al., 2018).

Figure 10. Academic Medical Center (AMC), Amsterdam, 1981-1985 the Netherlands Source: (Wagenaar et al., 2018)

Indeed, in the 21st multiple design alternatives have appeared and are briefly described in Table 1. The four models offer advantages and disadvantages but are based on the same hospital primarily processes. Usually, hospital projects use different approaches resulting in hybrid models (Wagenaar et al., 2018).

Table 1. Hospital design alternatives in the 21st Century

A. The Theme model	These large complexes are subdivided into quasi-separate hospitals that are still connected but focus on specific medical specialities such as mother and child and oncology, among others.
B. The center model	Buildings organized based on processes separating traffic routes between patients and staff.
C. Three flow model	Distinguishing between traffic flows of acute patients, which are fast and effective, and outpatients and in-patients, which are customer oriented.
D. Typological model	Hospitals are a generic composition of the following building types: hot floor (intensive medical and technological areas), hotel (nursing wards), office (outpatient functions), and factory (technical support functions).

Table 2. Evolution of hospital typologies.

Time	Typology	Issue solved
19^{th} Century	Corridor and Pavilion	A gradual expansion of the building by adding modules next to each other to enlarge the capacity of patients
1900 -1930	Large medical centers	Combination of medical functions with complementary activities
1936 -1955	T-type, H-Type, K-type	Use the distinction of medical functions to facilitate the future expansion of facilities.
1955 -1985	Wide foot – and low-rise hospitals	Additional medical departments were introduced together with new equipment—the emergence of atria as semi-public space.
21^{st} Century	Four models	The efficiency of logistical, economic, and social aspects

After describing hospital design through time, a summary of the evolution of hospital typologies with the main issues to be solved can be seen in Table 2. It can be concluded that the technological advancements of each era have influenced architectural design. However, there is no systematic research that relates hospital design typology to support primary hospital processes. Moreover, architects have not made a post-occupancy evaluation to assess to what extent design responds to hospital processes or understand which physical configuration is a better solution for the functional requirements.

2.2 Healthcare system in the Netherlands

In the Dutch healthcare system, the government has a regulatory role. It is constituted of three main actors, non-profit insurance companies, healthcare suppliers, and patients. Healthcare is paid by insurance funds which in turn negotiate services arrangements with healthcare suppliers. Since 1940, the national government of the Netherlands was responsible for ensuring healthcare services for the residents of the country, and the main objectives were quality, accessibility, and affordability. Moreover, the government was in charge of the construction of healthcare institutions until 2008, and due to alterations in the legislation of the political context, the former system where a centrally directed budget of healthcare real estate investment existed changed to a regulated market system through the basis of the Healthcare Facilities Law (Wet Toelating Ziekenhuisvoorzieningen: WTZi; Zwart, 2014).

Between 2008 and 2018, a transitional regime applied. After that, complete coverage of capital costs depended entirely on the care performance of the health organizations. If the vacancy of the buildings was high or the production of health does not generate enough income to cover the capital expenditures, financial problems arose for the private parties leading to possible bankruptcy. Furthermore, the decrease in the government's control on investment decisions and healthcare institutions' capacity meant an increasing power of banks and health insurance market parties since they provided loans to finance the building plans and purchased capacity (Zorgvisie, 2020).

The change in regulations resulted in increased risks and responsibilities for healthcare suppliers regarding real estate investment. Thus, ownership of the real estate and the provision of care was transferred to private parties. The objectives of this shift were to introduce more efficiency incentives to healthcare providers and give more freedom and responsibility to healthcare providers (Zorgvisie,2020; Zwart, 2014).

Currently, healthcare suppliers are empowered to finance, procure, and build projects independently and make their own autonomous decisions (Zwart, 2014). Due to the rapid technological development and high investment costs paid by healthcare providers, design requirements and physical configuration of facilities have been influenced, limiting buildings' size and seeking space optimization and flexibility to cope with technological advances and changing demands. Hospital boards influence the design and decision-making of new projects. Although many stakeholders are involved in the design process of hospital buildings, such as medical care experts and advisors, hospital board members can include additional requirements in the design brief.

2.3 Elements of hospital design and safety measures for infectious disease

In general, hospital buildings are composed of distinctive functional zones classified into four areas: 1. Outpatient clinic and public spaces, 2. The hot floor" consists of diagnostic facilities and treatment areas, 3. Patient wards, and 4. Logistical and back-office areas. Technical services and Information & Communication Technology (ICT) are distributed along the zones and intensely concentrated on the hot floor, where mainly technology-based functions are located. From a design process perspective, the program of requirements (PvE) is compiled in the brief of requirements. Then, the PvE of each area is translated into function and form. The creation of department adjacencies is developed (block diagrams), followed by the detailed design of each room. After the conceptual model, construction blueprints are created, adding equipment and technology planning (Reiling et al., 2004).

The hot floor is one of the more complex and expensive areas to design in hospitals. It contains functions such as emergency department, operating theatres, recovery rooms, ICU, pressured and isolation rooms. Treatment of infectious and bacteria diseases are carried out in this area. Hence, the spaces must comply with complex technical and spatial requirements such as ventilation systems, ICT, and telemetry monitoring to properly function and contain the diseases (Herweijer, 2020). Additional sluice rooms are necessary to provide a means for the efficient disposal of waste products generated by patients and lower the high risks of spreading a virus or a contagious disease. However, this solution increases the cost of the facilities and involves additional protocols for medical staff.

Moreover, multiple traffic flows such as care logistics, materials, supplies, and medical instruments can be distinguished in hospitals. Care logistics can be classified into two categories of patients flows. The first group comprises the outpatient clinic users who often come accompanied by a person to diagnose or treat and then return home. The second group is hospitalized patients, who need to be moved by nursing staff to analyze and treatment areas. In normal circumstances, the first category generates a more significant traffic flow. It is the fastest-growing group of patients that come for day treatment, such as oncology and surgical interventions. The traditional patient flow can be seen in figure 11.

Figure 11. Regular patients flow. Source: Own diagram

During an acute situation such as COVID-19, changes in processes, logistics and operations have occurred to respond to the pandemic requirements. However, hospitals are designed so that the isolation and separation of infected and non-infected patients are possible. The scale of the pandemic in the first wave overwhelmed the ICUs and Isolation rooms very quickly.

As mentioned in chapter 1, changes in the traffic routes had to be arranged to avoid streams of contaminated patients overlapping with other activities. Such to lower the risk of the spread of the contagious disease.

Accordingly, the interdependency of functions and interference of different traffic flows imply that safety-driven design principles for controlling an infectious disease should be met across and within departments (Reiling et al., 2004). Not only involving safety measures in isolation rooms and surgery rooms is enough but also waiting for areas, nursing wards, and corridors.

Moreover, the typology of patient's wards used in the healthcare facility's design can also control the spread of an infectious disease. For example, during the first wave of the COVID-19, no medical staff was infected by patients with coronavirus in Erasmus Medical Center. The high-quality care supported by the provision of 100% single-patient rooms represented consistent design safety principles in a standardized and uniform manner (van Heel, 2020). The conditions of the spread of the virus would have been different if the design layout consisted of multiple patient rooms since patients would have been more exposed and vulnerable to the virus.

Safe traffic flows and control of infectious diseases can influence the department's location, adjacencies, and internal design of specific areas that all together determine a hospital's layout (Reiling et al., 2004). However, more research about design decision-making based on safety principles is necessary to reduce the risk of infection in healthcare facilities and ensure a safe environment for end-users. Hospital design has the challenge of prioritizing patients and staff's safety and well-being while achieving the technological, operational and logistics requirements (Ramboll, 2021).

2.4 Elements of hospital design – Flexibility

As it was explained in chapter 2.1, technological development has made delivered care change rapidly over time. It has also demanded that hospitals' architectural design respond to changes such as the development of new medical departments or accommodating new medical equipment. Thus, flexibility has become an additional requirement in hospital design to comply with the evolution of medical knowledge.

Nevertheless, healthcare facilities should respond to technology changes and accommodate emergent and unexpected needs due to possible outbreaks such as COVID-19 (HKS, 2020; WSP, 2020; Nanda et al., 2020). The first wave of the pandemic underlined the importance of having a more flexible and versatile infrastructure to enable healthcare professionals to react and adapt quickly to coming events while still providing all the services required in a hospital (Murphy, 2020).

According to Schmidt III, R., Eguchi, T., Austin, S., & Gibb, A. (2010), flexibility can be understood as "the capacity of a building to accommodate the evolving demands of its context effectively, thus maximizing value through life". Flexibility is a broad concept, and consequently, multiple perspectives are used by designers and practitioners in the field. Monahan (2002) states that flexibility can be deconstructed in five spatial properties, as shown in figure 12: versatility, modifiability, convertibility, scalability, and fluidity. Versatility and modifiability relate to operational changes that can occur on a short-term basis, daily or weekly, and don't require structural changes. In contrast, convertibility and scalability involve a more long-term perspective. Significant changes such as expansion or reconfiguration should be done (CADRE, 2015).

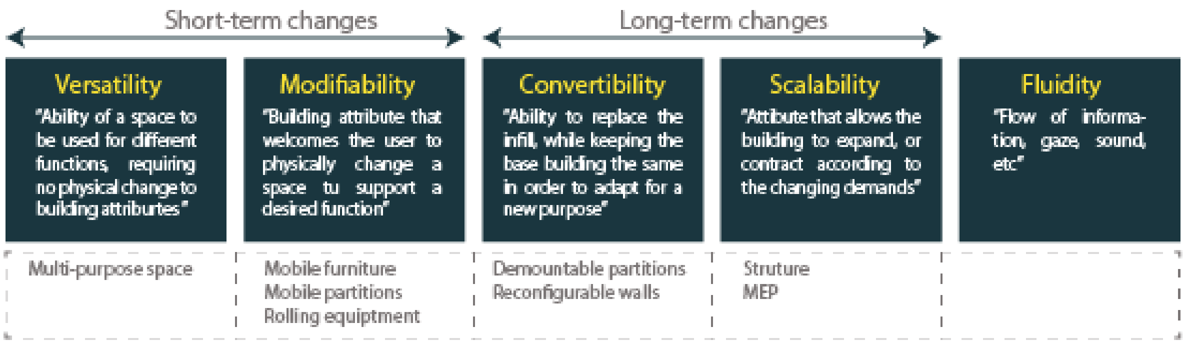

Figure 12. Five spatial properties of the flexibility concept. Source:(CADRE, 2015)

Hospitals are complex projects with low adaptive capacity and expensive to adequate in unforeseen circumstances (Nanda et al., 2020; WSP, 2020; McQuillan, 2020). Nonetheless, during the COVID-19 outbreak, some examples of Dutch hospitals evidenced flexibility when responding to the surge event.

Example versatility and scalability

Versatility accounts for immediate multifunctional use. An example of this is the Reinier de Graaf hospital in Delft, where the whole department of lung diseases was allocated to COVID-19 care. The medical department had all the required equipment and installations for COVID-19 care, functioning as a multipurpose space that helped medical staff scale up the capacity of the healthcare facility very quickly.

Example modifiability and scalability

Modifiability accounts for a fast reconfiguration. As explained in section 1.2, the 8th floor of the cardiac & pulmonary department of the Erasmus Medical Center was refurbished to 40 temporary COVID-19 ICU in two weeks. The modification is an example of the spatial principle of modifiability, and it was possible due to the physical and technical characteristics of the space. The standardized distribution of a single patient room of the whole project, together with the telemetry and monitoring infrastructure ready to be used, facilitated the repurposing of patient's wards into ICU corona care. Some building and technical adjustments were made to increase the capacity and set up quickly the desired function.

2.5 Research questions

As explained in section 2.3, there is no systematic research regarding design decisions influenced by COVID-19. Therefore, this explorative study aims to gain insight into the experience of the current pandemic by evaluating how hospitals performed during the different waves and study the essential measures to future-proof hospital design to a virus-like COVID-19. Therefore, the following research sub-questions were formulated:

1. What is the relationship between the spatial characteristics of existing hospitals in the Netherlands and the safety measures taken by them during the different phases of the COVID-19 pandemic?

2. Based on the pandemic experience, what interventions should be considered in hospital design to future-proof projects to virus-like covid-19?

The conceptual model in figure 13 illustrates the multiple challenges of hospital design evoked by the input of the COVID-19 pandemic and show graphically how the concepts explained in the last chapters relate to each other. The output is to build towards more resilient healthcare projects. The grey boxes of the conceptual model represent other aspects that should be considered for achieving future-proof healthcare projects. This research is focused on the category of space and the physical environment of hospitals.

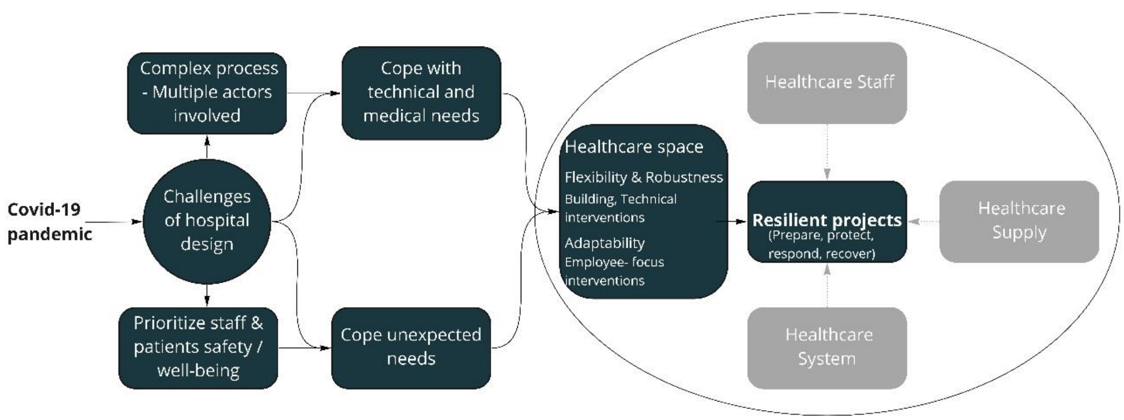

Figure 13. Conceptual model Source: Own diagram

03
Study design

3. Study design

A qualitative approach will be used to meet the aim of the research. First, a questionnaire focused on facility and real estate managers was structured using the concepts described in chapter 1.2. After, additional follow-up in-depth interviews with selected respondents from the survey will be made to understand further how hospitals dealt with the different stages of the pandemic and what lessons can be transferred to future hospital projects to have more resilient healthcare facilities to virus-like COVID-19.

Figure 14. Qualitative approach. Own diagram

3.1 Practice-based research

According to Gherardi (2012), the practice-based study evolved to a way of qualitative research, which in turn can be defined as a "research strategy that emphasizes words rather than quantification in the collection and analysis of data" (Bryman,2012). The main steps in qualitative research can be seen in figure 15.

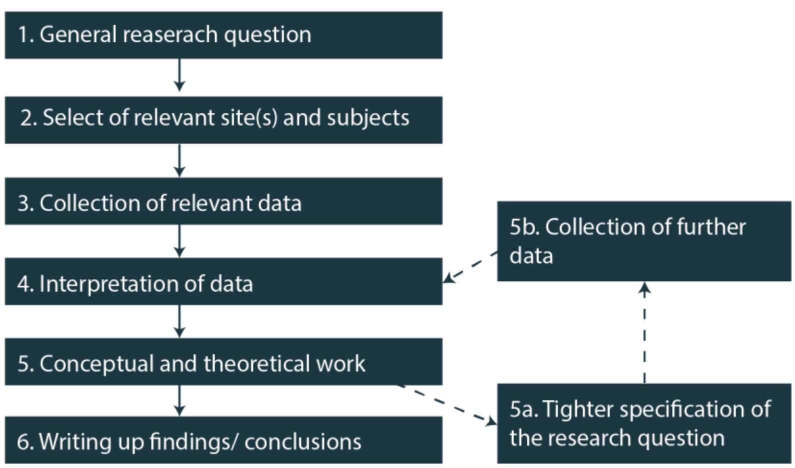

Figure 15. Steps in qualitative research. Source:(Bryman, 2012)

5.5 Research methods & participants

The questionnaire is the main starting point that will provide a national-based overview of the pandemic preparedness and the adaptations made to the hospital buildings during the different phases of the outbreak. Some of the advantages of using a survey are that it can be distributed in substantial quantities simultaneously, short in length, and easy to fill out since mostly there are close-ended questions. Furthermore, the survey is convenient for respondents, considering they can complete it at any time and at their desired speed (Bryman, 2012).

The database of the RIVM (National Institute for Public Health and the Environment) with 68 health organizations composed of 117 hospitals was used and complemented with the LinkedIn profile of professionals in the field of facility and real estate management of hospitals in the Netherlands. The survey was distributed via e-mail and LinkedIn in collaboration with the supervisors from TU Delft and the account managers from the healthcare department of the engineering company to enlarge the response rate. Respondents received a preliminary e-mail to make them aware of the research purposes and a link to the survey. Additionally, the survey was advertised for two weeks on the website of FMT Gezondheidszorg magazine to increase the rate of response. The questionnaire was developed on Qualtrics software; it is approximately 10 minutes long and focuses on the hospital working practices and building adaptations during the COVID-19 pandemic. The questionnaire is further explained in section 3.3.

Additionally, to better understand the survey outcomes, in-depth interviews with selected participants from the survey are suggested as a second method to collect qualitative data. This method has a flexible structure. The initial research ideas are more open-ended and offer the possibility to reflect on the crisis period, understanding more about the decision-making process and choices regarding planning and adaptations made. In this approach, there is a higher interest in the interviewees' perceptions and obtaining detailed answers on how the interviewee understands or considers important specific issues or events (Bryman, 2012).

Therefore, online video interviews will be developed with professionals responsible for the hospital buildings operations, such as facility managers. The aim is to understand the context of the emergency response during the pandemic and investigate new emerging initiatives after the crisis that could contribute to future-proof healthcare facilities to a virus-like COVID-19. All interviews will be anonymized and recorded with the previous consent of the respondents.

5.5 Questionnaire description "Your hospital during COVID-19"

The survey questions (see appendix A) are organized into four main sections where only general information about working practices during the COVID-19 pandemic was asked. Basic hospital building characteristics like building year, address, and type of hospital were included in the RIVM database beforehand, so respondents do not lose time filling out this type of information. Moreover, context-related questions about the pandemic response were included in the in-depth interviews.

As table 3 shows, the first section accounts for the general information of the respondent; the second part is about the working practices during COVID-19, general characteristics of the facilities, and the preparedness for the pandemic. Section three is centered on the different adaptations made to the buildings to respond to the outbreak. Finally, the fourth part is about the emerging initiatives after the pandemic experience. The sections are further explained below:

Table 3. Survey sections

I. General information

Questions about the respondents aim to collect non-identifiable data but help to characterize the respondents.

II. Outcomes measures:

a. Working practices – Operations during COVID-19

- Ways of working: Cohort nursing and non-cohort
- Distinguished locations: facilities dedicated 100% to COVID care and non-COVID
- Capacity approach: Outplacement of patients

b. Hospital characteristics (objectives outcome measures)

- Number of beds
- Number of ICU
- Number of single-patient rooms

c. Pandemic preparedness (Subjective outcome measures)

- Pandemic preparedness 1st wave
- Pandemic preparedness 2nd wave
- Pandemic preparedness British variant – 3rd wave

III. Measures are taken during the pandemic

These variables influence outcome measures and are classified into three main categories composed of eight or nine interventions.

- Building interventions
- Technical interventions
- Staff services

IV. Future overview

This section aims to reflect on the future necessities of future-proof healthcare facilities to a virus-like COVID-19.

The survey results are expected to provide an overview of the measures taken in Dutch hospitals. The findings chapter will analyse the relationship between the emergency response measures and the spatial characteristics of hospitals, like building year, type of hospital and urban density. Furthermore, with the last questions from the survey, it is expected to create a first overview of what elements should be considered in future hospital design.

3.4 Interview protocol

The participants and questions of the interview were chosen based on previously gathered data of the survey. The idea during the sessions was to gain knowledge about the context of the emergency response and the decision-making process. The goal was to reflect on the crisis period investigate the main difficulties and lessons learned during the experience of each organization. The interview protocol was set up, taking into consideration four main topics shown in table 4. The full interview protocol can be found in appendix B.

Table 4. Main interview topics

1. Context crisis preparation 2. Strategies & policies made during the emergency response. 3. Changes in logistics 4. Long term perspective of facilities

3.5 Processing data

For the visualization and descriptive analysis of the data collected in the questionnaire, Tableau software is proposed to be used. Timelines and histograms are used to find patterns and visualize the data collected in the survey. No further statistical analyses were done, and therefore the analyses of the survey analyses are to be considered a qualitative analysis.

An explorative inductive approach depicted in figure 16 will be used to analyse the interviews since little is known about the study phenomenon. This approach involves analyzing the data with little or no predetermined theory, structure, or framework and uses the interview data to answer the research questions, offering the possibility for interpretation (Burnard et al., 2008).

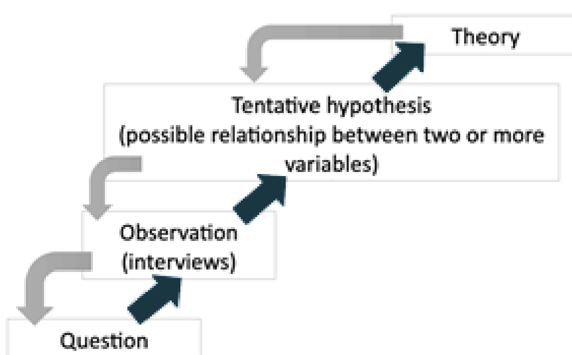

Figure 16. Inductive approach structure. Source:(Koolwijk, 2020)

After each interview session, all interviews in English will be transcript and labelled using the software ATLAS.ti. This tool is used to manage and help analyze the collected data through the thematic content analysis technique. Open thematic coding will be the main tools to analyze the transcripts, identify themes, categories, and relations between variables of interest in the research to create tentative hypotheses and advice for future hospital design (Burnard et al., 2008).

Research process

Figure 17 illustrate the research process. The first part depicts the initiative phase, involving the problem formulation, the relevance of the research, and the background information, which is finalized with the formulation of the aim and objectives of the research. The second part explains the study design; the research consists of a practice-based interpretative investigation focused on facility and real estate managers of hospitals in the Netherlands with a qualitative methodology approach. First, a survey will be conducted, and then in-depth interviewing will be used. After that, the data will be processed and analyzed to answer the research questions. Finally, the main findings will be summarized and discussed. Finally, a reflection of the process will be done, followed by recommendations for future research in the field. Additionally, a planning schedule overview is depicted in appendix c.

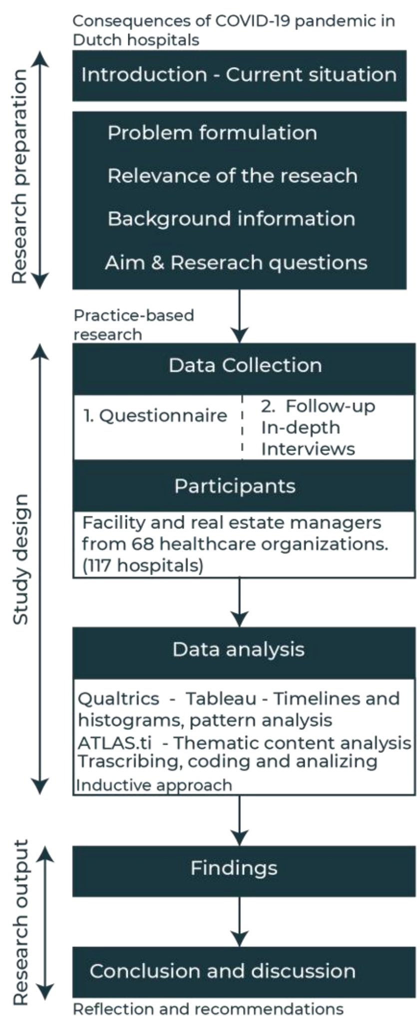

Figure 17. Research process. Source: own diagram

04
Findings

4. Findings

4.1 Results from the survey

The survey was published on March 23rd, and the objective was to reach the 68 hospitals included in the RIVM database. There were contacted 27 hospital managers by e-mail, 68 request connections were sent through LinkedIn with the link to the survey. Additionally, to increase the response rate, the questionnaire was published for two weeks on the website of the FMT Gezondheidszorg magazine. As a result, there were 38 responses, obtaining a net response rate of 56%.

Descriptive information

As shown in figure 18, real estate managers answered the survey (24%), facility and real estate directors (20%), facility managers (8%), logistic manager (2%), and other professionals like project managers, consultants, head of engineering and construction and director of infection prevention among others (42%). On average, the employees have worked in their current position for nine years. The level of education can be seen in figure 19. The educational level of HBO (53.33%), WO- Masters/PhD (40%), other (6.67%).

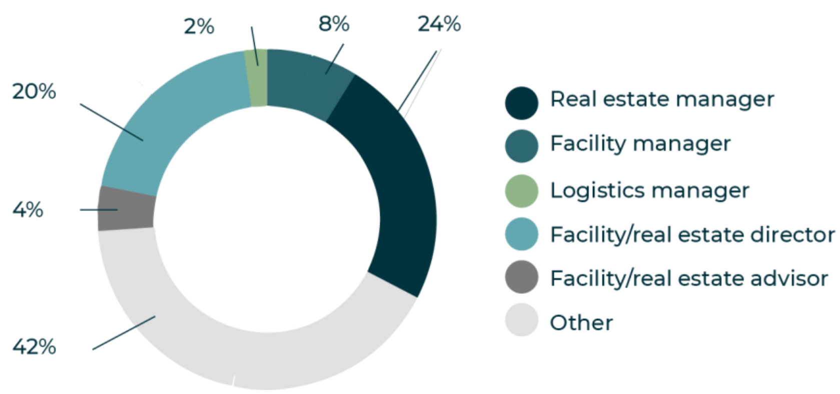

Figure 18. Respondents' profession distribution

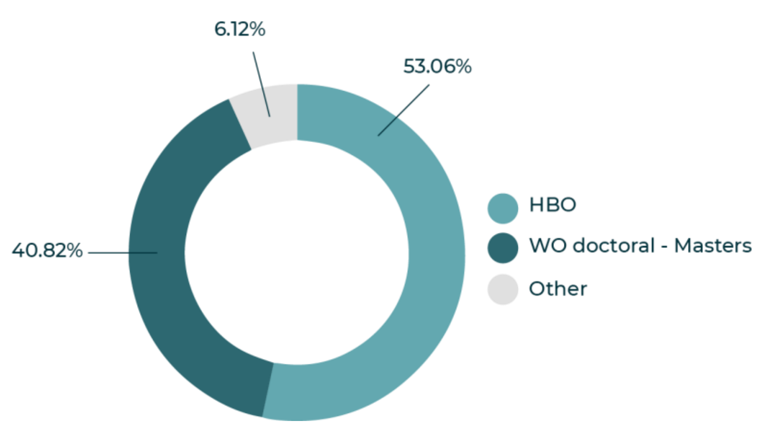

Figure 19. Respondents' education distribution

Figure 20. shows the hospitals that answered the survey with a zip code registered in the RIVM database. There were 30 spread responses over the territory, which is beneficial to have a general picture of the pandemic response in the Netherlands.

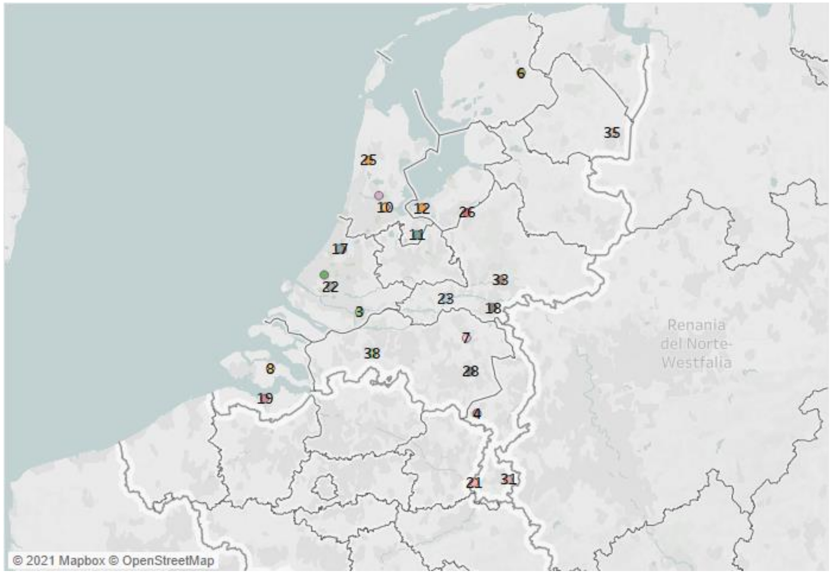

Figure 20. Location of hospitals that answered the survey with zip code registered in the RIVM database. Source: own diagram

4.2 Findings research question 1

<u>What is the relationship between the spatial characteristics of existing hospitals in the Netherlands and the safety measures taken by them during the different phases of the COVID-19 pandemic?</u>

4.2.1 Introduction safety measures

Data about the safety measures implemented by Dutch hospitals in the three waves of the pandemic was collected in the survey. The following three safety measures were defined: building interventions, technical interventions, and employee-focused interventions. There were defined around ten sub-interventions inside each category, and each respondent should answer the month of implementation.

The three types of safety measures and their sub-interventions can be related to the concepts of flexibility, robustness, and adaptability. Flexibility can be deconstructed in the four spatial properties defined by Monahan (2002): versatility, modifiability, convertibility, and scalability. Robustness accounts for the possibility to respond to changes and adapt the facility to coming events. Hence, the building and technical interventions are related to the physical configuration adaptation and can be associated with flexibility, its four aspects, and the concept of robustness.

Moreover, some employee-focused interventions are also linked to the building itself. However, the majority are related to services modifications, which is associated with the concept of adaptability. In this research, adaptability accounts for the provision of services for the healthcare workers during the pandemic to support care delivery. Figure 21. shows the relations between the types of measures, the correspondent sub-interventions, and the concepts of flexibility, robustness, and adaptability.

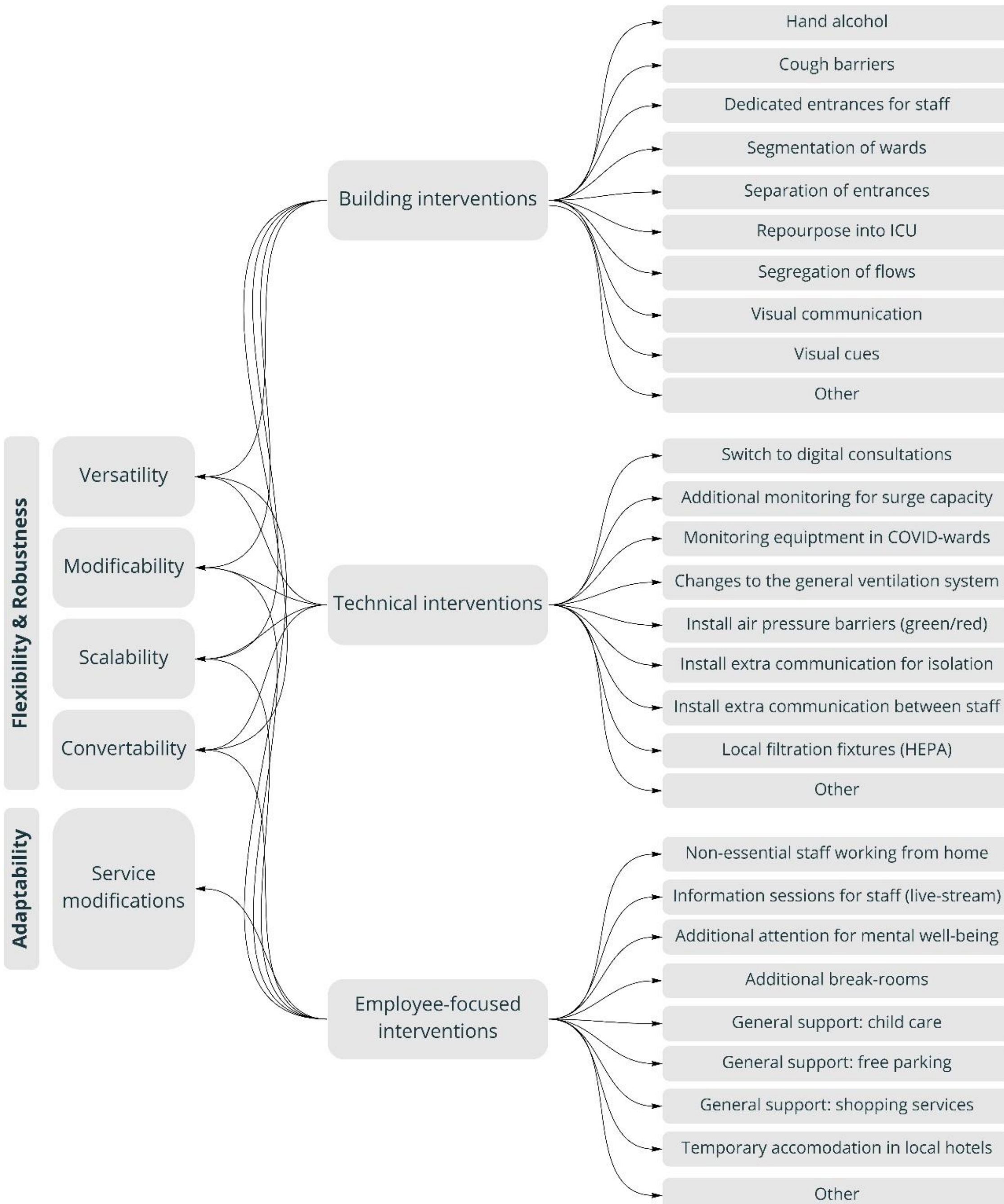

Figure 21. Relations safety measures and sub-interventions with the concepts of flexibility and adaptability.
Source: own diagram

4.2.2 Introduction spatial characteristics

Spatial characteristics of hospitals in the Netherlands were used as the criteria to determine the relations between the buildings and the safety measures taken during the different waves of the pandemic response. Initially, the objective was to consider criteria associated with the working practices during the pandemic, such as cohort nursing for COVID care, collaboration with other care organizations to free up beds for covid patients, and distinction of locations between 100% dedicated covid and non-covid care. However, after a preliminary analysis of the data collected from the survey, the previous outcome measures were not making a clear distinction between hospitals. Hence the spatial characteristics used for the study are only the following: 1. Type of hospital, 2. Building year and 3. Urban density explained in table 5.

Table 5. Criteria used for spatial characteristics of hospitals.

Criteria	Definition	Measurement
Type of hospital	The following types of hospitals exist in the Netherlands: academic, general, pediatric and outpatient clinic. Academic have to keep available capacity since they offer additional services like trauma and transplants. Payment systems work differently for each type.	• Academic Hospital • General hospital
Building year	In 2008 occurred a change in government policies that influenced real estate ownership and financing. This regulation limited the size of facilities and spatial requirements. The consequences of this regulation were evident a few years after the introduction of the new policy.	• Built before 2010. • Built after 2010
Urban density	Hospitals are located in regions with different urban characteristics that can influence the required services during the pandemic response. The urban density was assessed at the municipal level. Municipalities with a population density lower than 1,500/km^2 were defined as low urban areas, and municipalities with higher than 1,500/km^2 were considered high urban areas (Centraal Bureau voor de Statistiek CBS, 2021)	• Low urban • High Urban

The hospitals that answered the survey were classified according to the three spatial characteristics previously explained. Figure 22 shows the distribution by type of hospital of the sample. 63.16% are general hospitals, and 15.79% are academic hospitals. 21.05% of the respondents are not part of the RIVM database; any of these respondents answered questions about safety measures.

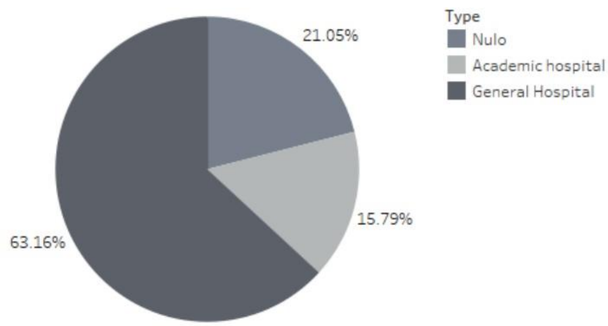

Figure 22. Distribution by type of hospital. Source: own diagram

The distribution by building year is depicted in Figure 23. The hospitals built before 2010 correspond to 63.16% of the total that answered the survey, and 15.79% conform the facilities constructed after 2010.

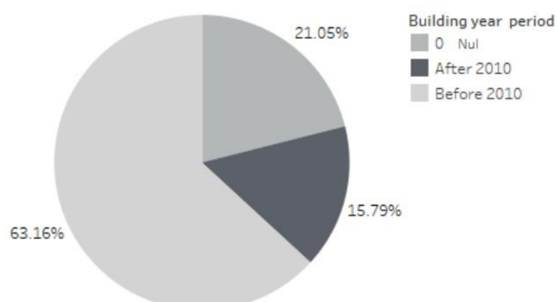

Figure 23. Distribution by building year of the hospitals. Source: own diagram

The pie chart of figure 24 represents the proportion of hospitals located in high urban areas are 52.63%, and the ones found in low urban areas are 26.32%.

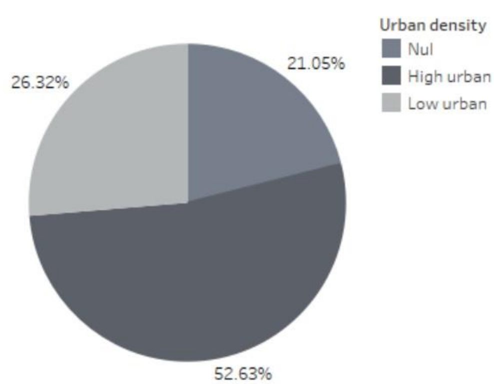

Figure 24. Distribution of hospitals by urban density. Source: own diagram

4.2.3 General pattern analysis

General timelines of building, technical and employee-focused measures are shown below in figures 25,26 and 27 to overview the interventions made during the pandemic response. The median per sub-intervention was calculated, and the responses were organized from lower to higher in these graphs. Each of the hospitals that answered the survey was plotted with a color. A code was assigned to keep anonymized the results. The measures implemented are represented graphically by a closed circle and not implemented with an open ring. Lastly, the percentage accounts for the hospitals that implemented that measure on the right of the graph.

Generally, it can be highlighted that hospitals implemented all sub-interventions during the pandemic response, and even some hospitals included some additional measures. As the graphs show, most of the interventions were carried out on the first wave, during March and April 2020, for all three categories. Figure 28 complement the timelines and shows the distribution of the safety measures per category over time. Moreover, it also shows that the proportion between building interventions, technical modification, and staff services is very similar between March 2020 and April 2020. Nevertheless, buildings modifications were the most implemented over time.

Regarding the building measures, hospitals have done modifications frequent in the three waves. Most of the hospitals did the interventions in March, April, and May 2020. Later in August, some hospitals made modifications right before the beginning of the second wave. During September 2020 and April 2021, hospitals also reported adjustments. Based on figure 25, hospitals' most implemented measures were hand alcohol, segmentation of wards, and visual cues. Although, the remaining six measures were also enforced by more than 50% of the respondents.

As figure 26 shows, technical measures are registered only in the first and second wave. Most of them in March, April, May, and June; some hospitals did changes in the second wave until October, but to a lesser extent. The most implemented measure was to switch to digital consultations and additional monitoring for ICU capacity. The less implemented was local filtration fixtures (HEPA).

Moreover, according to figure 27. hospitals registered the adaptations of services for staff mainly in the first wave in March, April, and May. Then some hospitals recorded adjustments in September and November. The most implemented measure was non-essential staff working from home and additional attention for wellbeing and information sessions. The service less provided was temporary accommodation in local hotels.

In sections 4.2.4, 4.2.5. and 4.2.6, timelines and histograms were made using spatial characteristics to differentiate the safety measures by groups of hospitals.

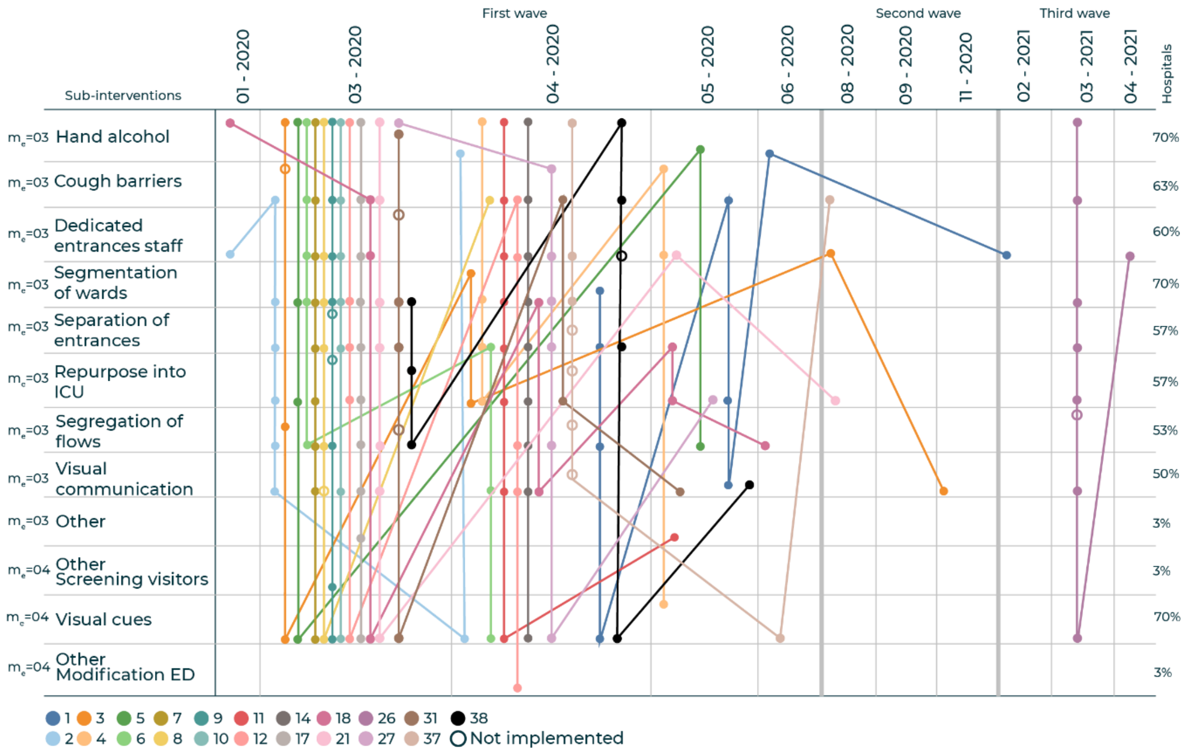

Figure 25. Timeline building interventions. Source: own diagram

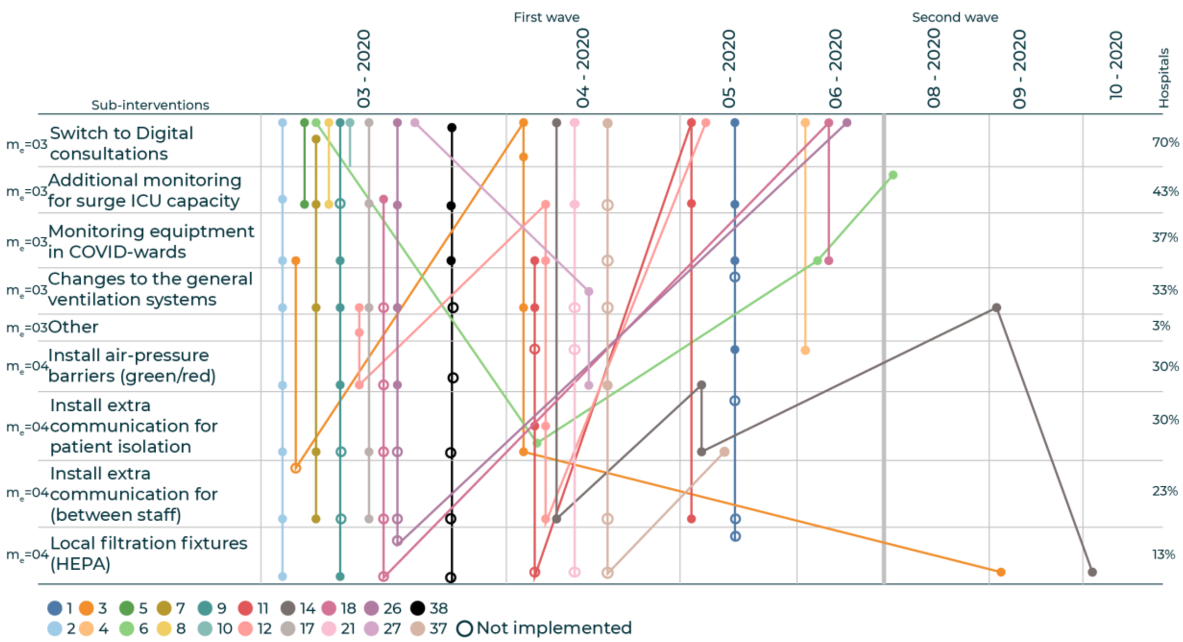

Figure 26. Timeline technical interventions. Source: own diagram

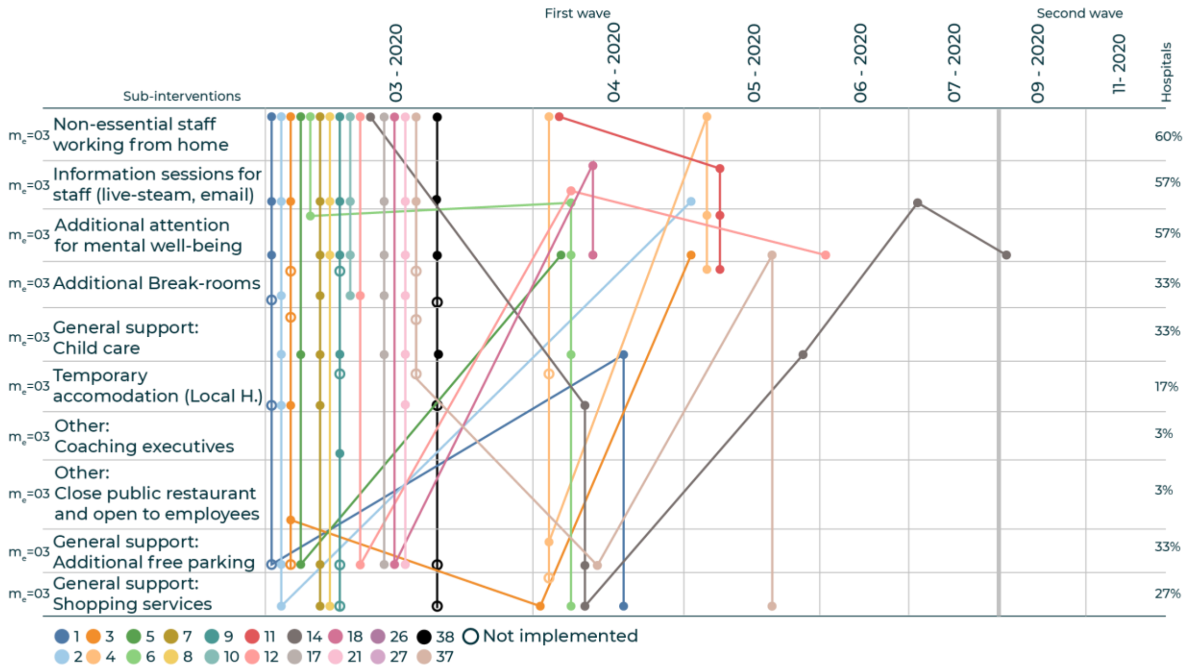

Figure 27. Timeline employee-focused interventions. Source: own diagram

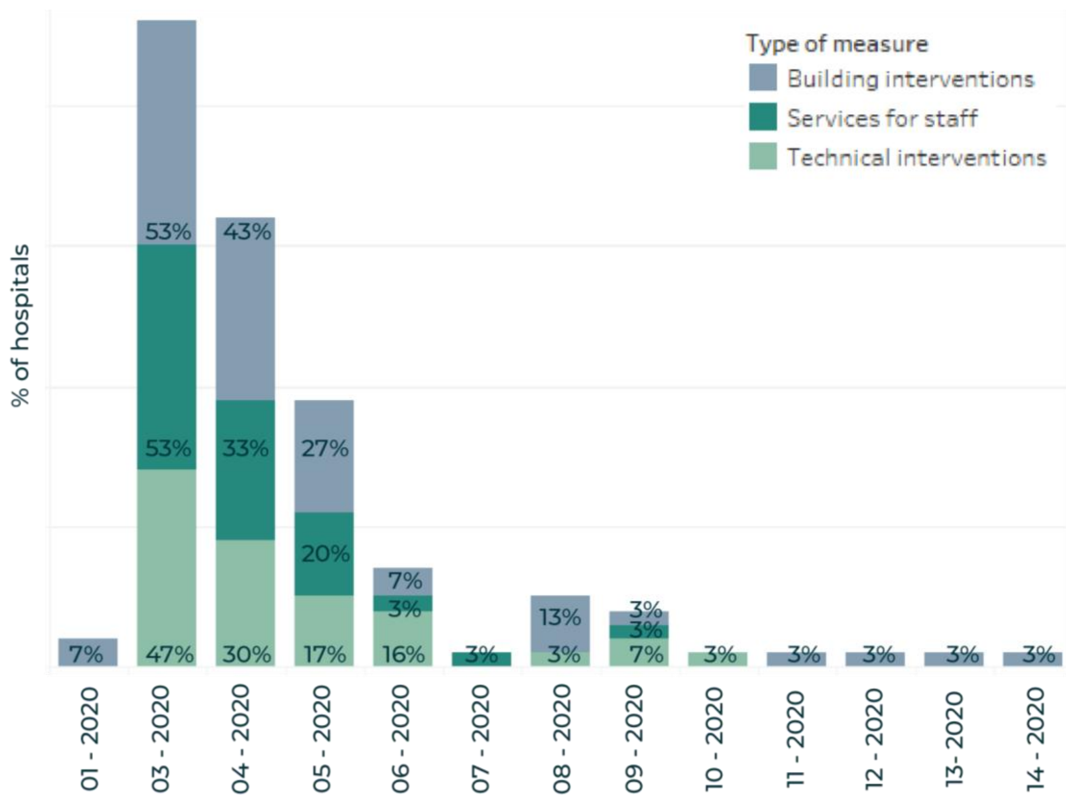

Figure 28. Distribution of measures by type over time Source: own diagram

4.2.4 Building interventions

Type of hospital

Figures 29 and 30 show the building interventions implemented in time, differentiated by the type of hospital. Most academic hospitals took the measures in March of 2020, a few in April and some adaptations were made at the second wave. In comparison, more general hospitals took the measures frequently in the three waves. March, April, and May were busy months. Even in April 2021, general hospitals continued making adaptations to their facilities.

As depicted in figure 30, most academic hospitals started in March 2020 with visual cues, segmentation of wards and hand alcohol. Then most hospitals segregated flows and Installed cough barriers. On the other hand, most general hospitals started with hand alcohol at first, then segmented wards and installed visual cues.

Furthermore, the findings in figure 31 evidenced that academic hospitals did the nine categories of building measures homogeneously. In contrast, general hospitals presented some less implemented actions: Separation of entrances, repurpose of wards and enhanced visual communication.

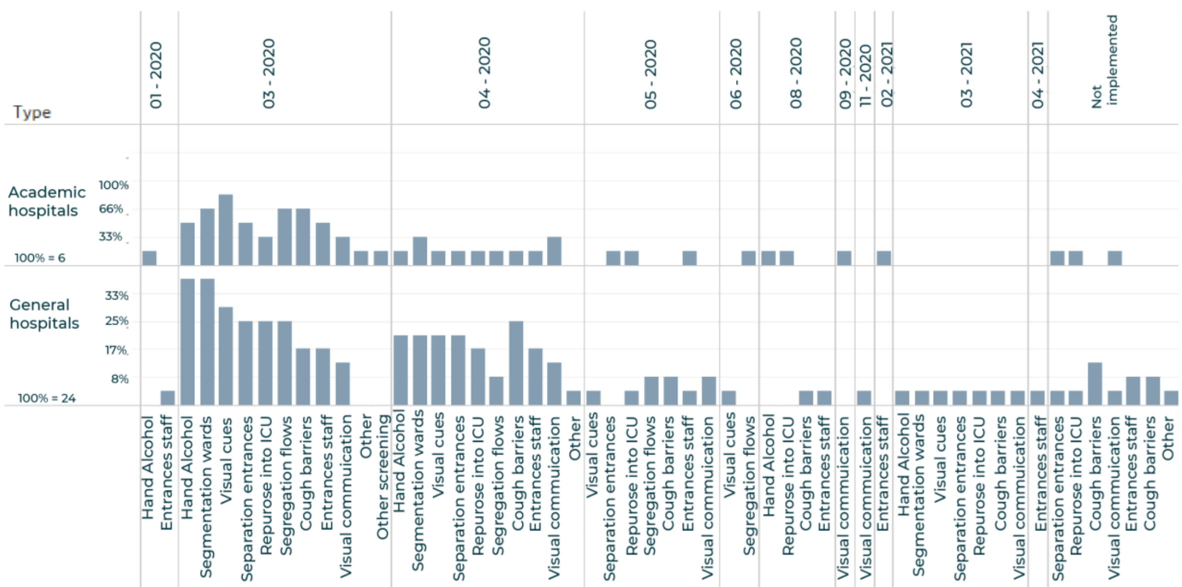

Figure 29. Building interventions in time by type of hospital. Source: own diagram

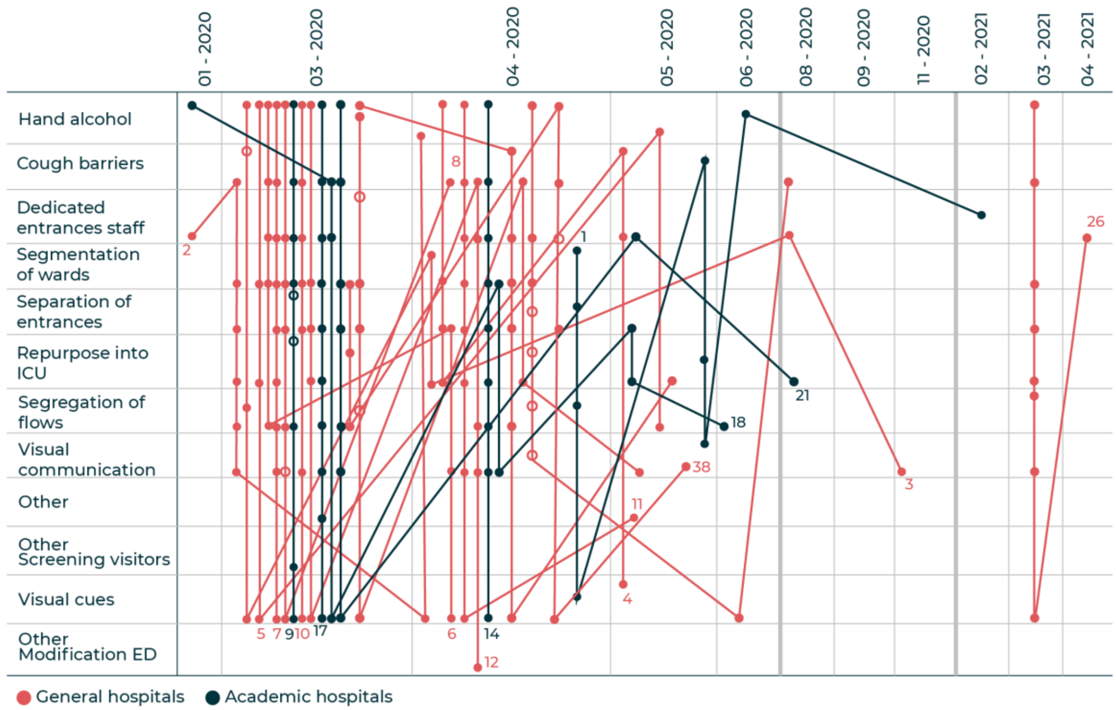

Figure 30. Timeline of building interventions by type of hospital. Source: own diagram

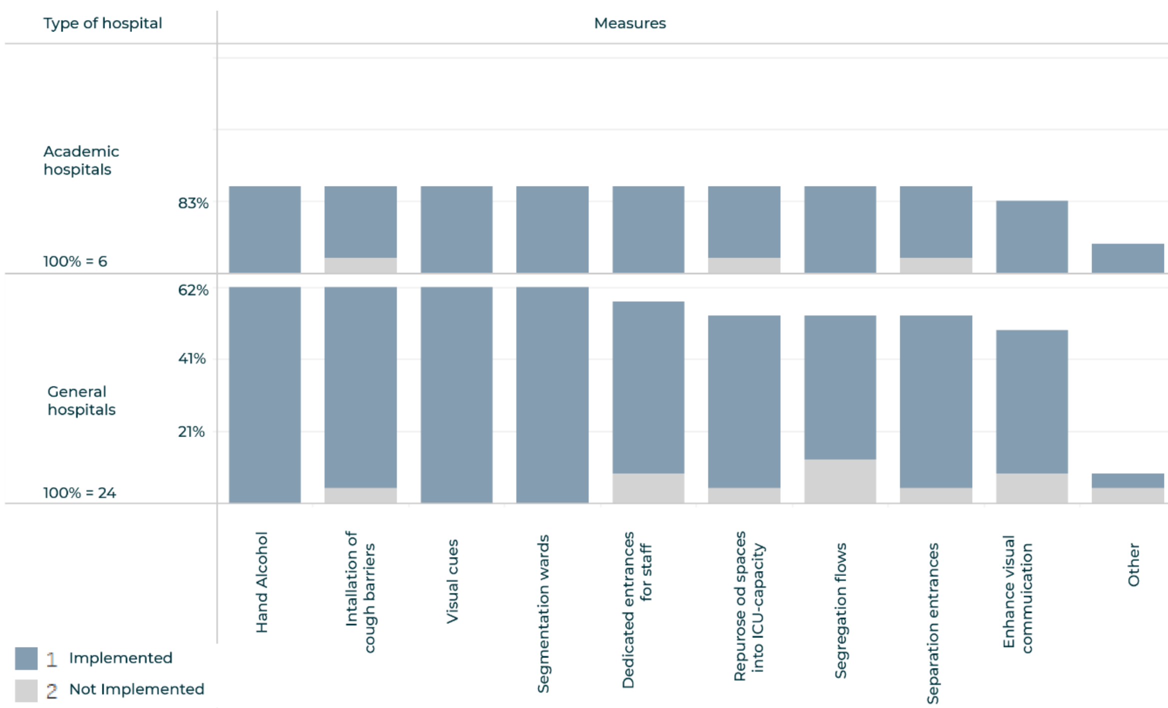

Figure 31. Building interventions by type of hospital. Source: own diagram

Building year

Measures were also differentiated by building year. Based on figures 32 and 33. It can be said that most hospitals constructed after 2010 took the actions in the first wave, notably in March. During the other waves, hospitals did some interventions like enhance visual communication before the second wave or entrances for staff before the third wave, but not in a persistent way. In contrast, hospitals built before 2010 have taken more measures over time. During the first wave, they took most of the actions during March and April evenly. Adjustments were also made in high frequency in May, June, and August. Furthermore, in the 2nd and 3rd wave, hospitals also made modifications.

Figure 34 shows that hospitals built after 2010 took all the measures in similar proportions; however, the facilities built before 2010, fewer hospitals repurposed spaces into ICU, segregated flows, entrances and had to enhance visual communication with infected patients. This might be because hospitals built before 2010 have more surface area than those affected by the 2008 government policy.

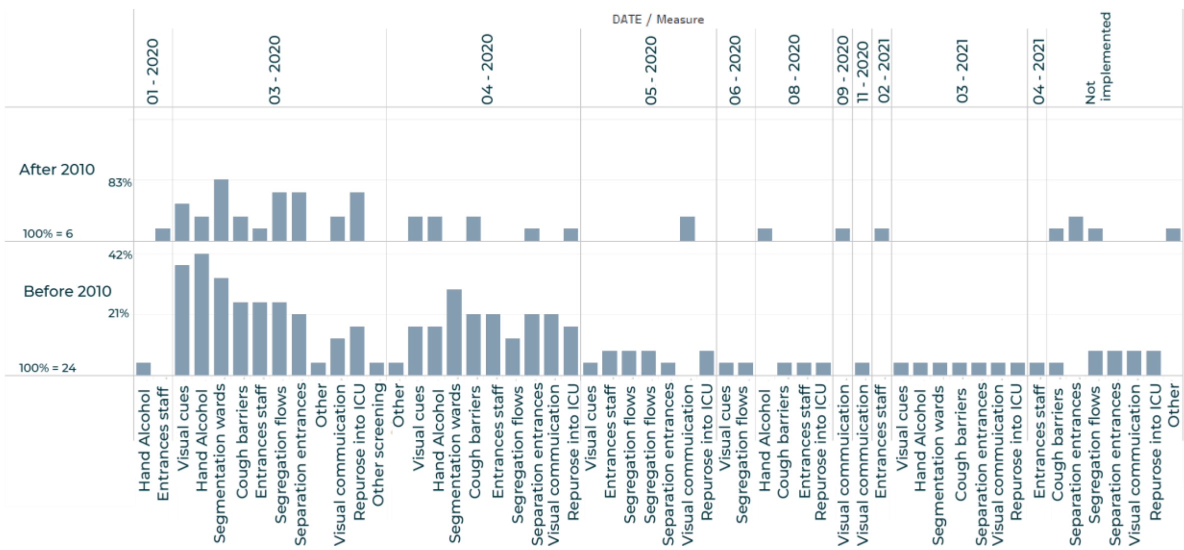

Figure 32. Building interventions in time by building year. Source: own diagram

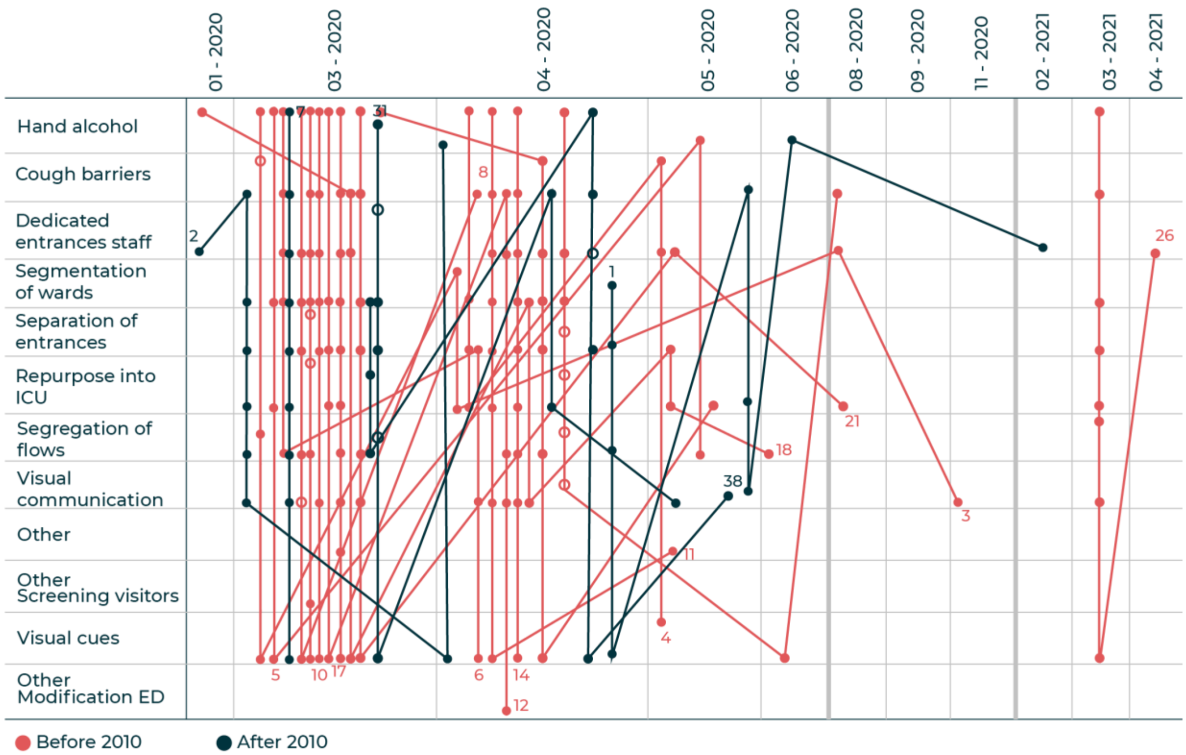

Figure 33. Timeline of building interventions by building year. Source: own diagram

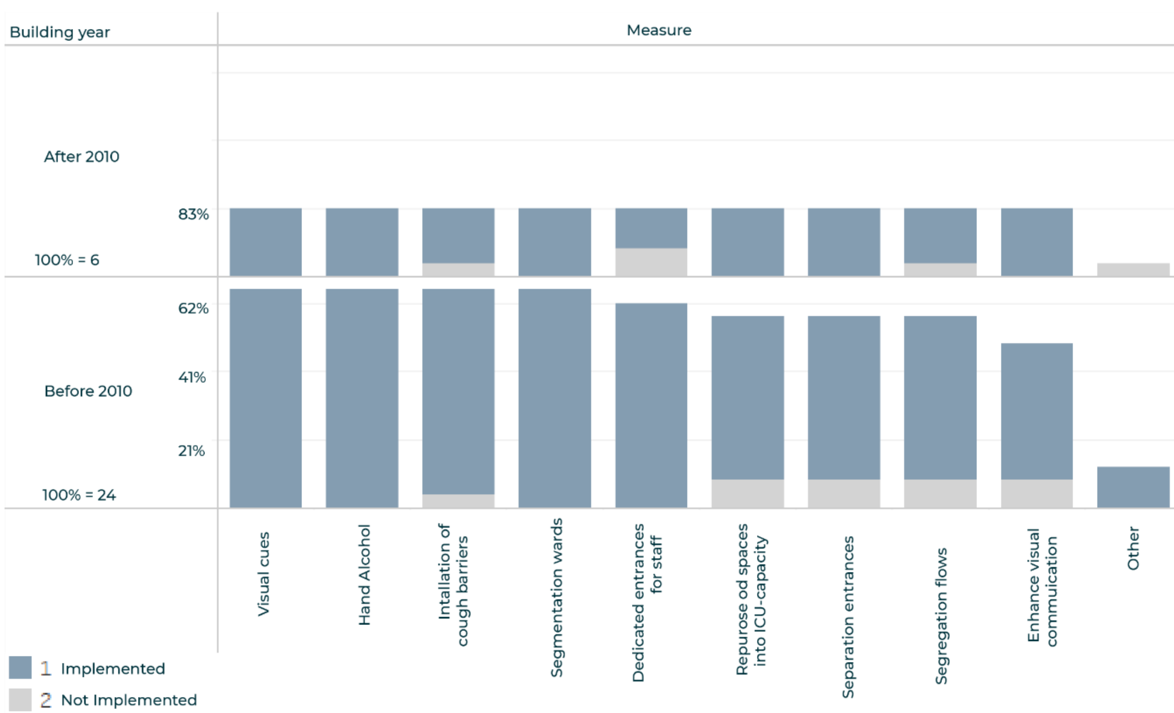

Figure 34. Building interventions by building year. Source: own diagram

Urban density

As plotted in graphs 35 and 36, hospitals located in low urban areas did building interventions mainly in the first wave, during March and April. Some hospitals took measures in May, and one hospital did all the building interventions in March of 2021 since it might not be in the pandemic heart; however, the timeline does not seem very busy. In contrast, hospitals located in high urban areas made modifications to the buildings for the whole period. Most hospitals took measure at the beginning of the pandemic (March, April), later in May 2020 and June. Also, in the second wave in August, September and November, adjustments were made. Even at the beginning of the third wave in February 2021, some hospitals did interventions.

Figure 36 shows that in March 2020, the measures most implemented by hospitals located in high urban areas were (from higher to lower): visual cues, hand alcohol, segmentation of wards, separation of entrances, cough barriers, segregation of flows, repurpose space into ICU capacity and enhancing visual communication. On the other hand, the measures taken by hospitals in low urban municipalities evenly distributed. Furthermore, it can be highlighted from figure 37 that some hospitals in high urbanity implemented additional modifications like screening of visitors, extra changes in entrances and tents outside the hospital.

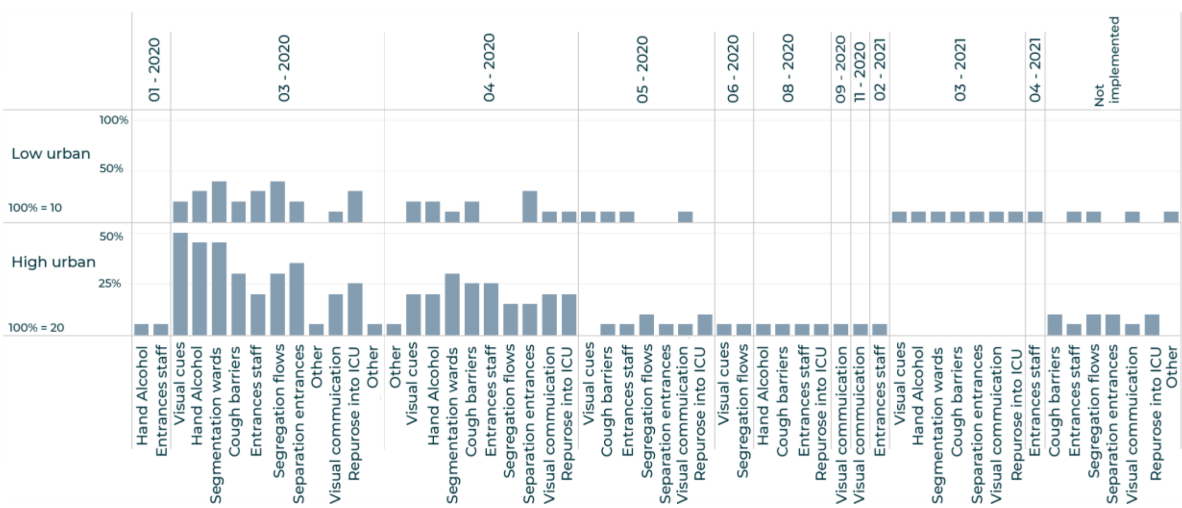

Figure 35. Building interventions in time by urban density. Source: own diagram

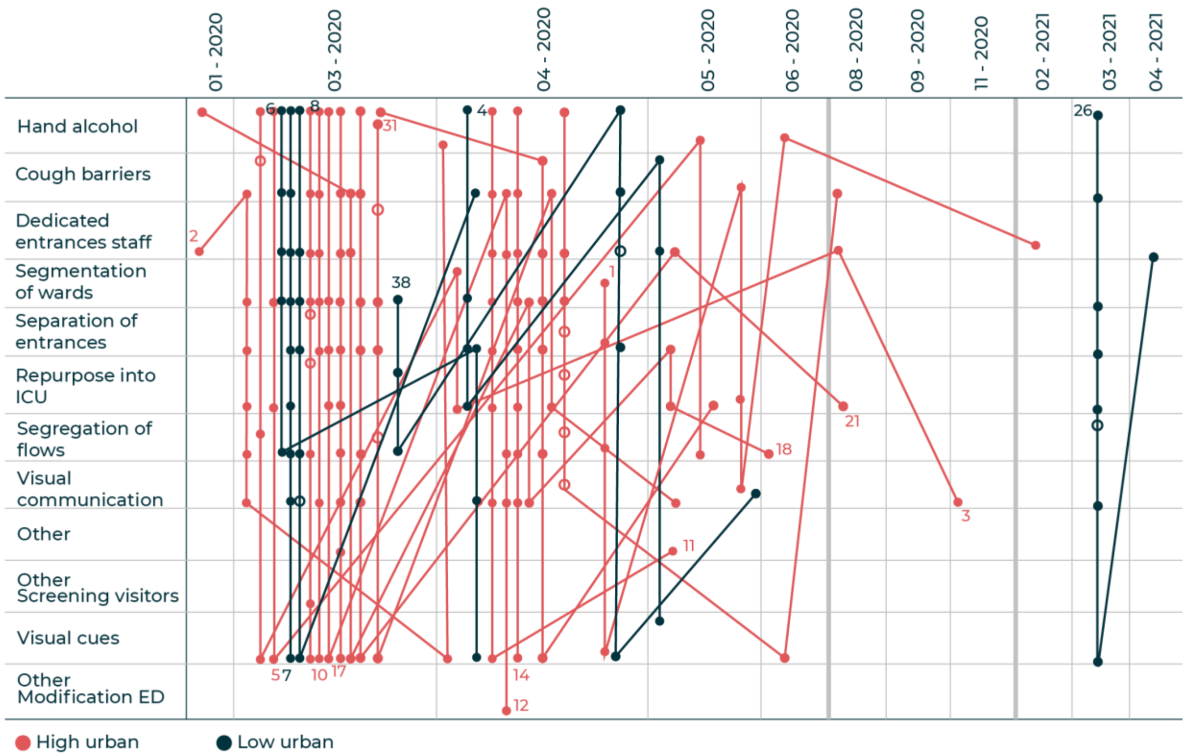

Figure 36. Timeline of building interventions by urban density. Source: own diagram

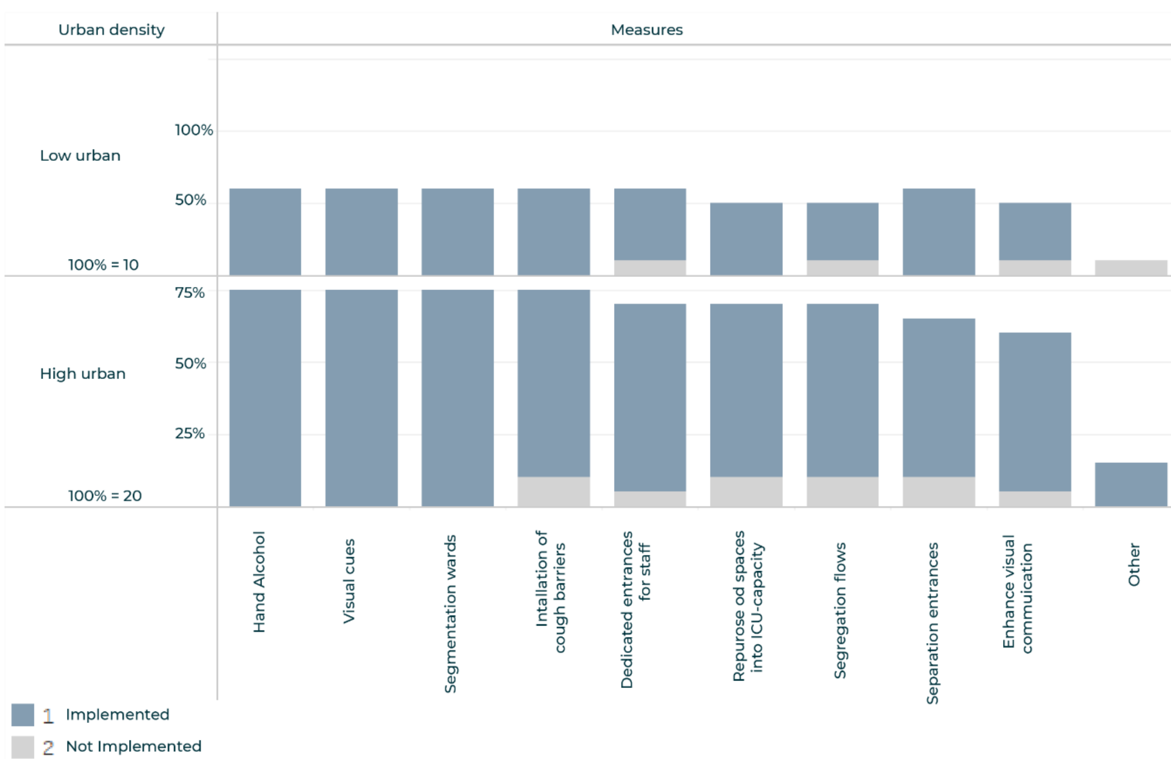

Figure 37. Building interventions by urban density. Source: own diagram

4.2.5 Technical interventions

Type of hospital

Technical interventions made by the type of hospitals shown in figures 38 and 39. It was found that in the academic type, most hospitals made technical modifications in the first wave during March and April. Fewer interventions were carried out in April, and a few hospitals took measures in May, June, and the second wave (September and October). Moreover, academic hospitals specified that some did not have to implement all the eight technical measures in the data collected. As indicated in figure 39 with the open circles, the educational type did fewer changes in the general ventilation system, installing air pressure barriers and HEPA filters.

On the other hand, the group of general hospitals registered more interventions through the different waves of the pandemic. Most hospitals did interventions in the first wave in March, but April, May, and June were also busy. Also, in the second wave, a local filtration fixture was recorded.

Additionally, figure 40 shows that the most implemented action for both categories was to switch to digital consultation in the first place. For the academic type, the second place was advanced monitoring equipment in COVID-wards followed by the Installation of communication systems between staff. In contrast, the second place for general hospitals was for additional monitoring for ICU capacity, changes to general ventilation systems, and installing extra communication systems for patient isolation. The least implemented measure was local filtration fixtures (HEPA). Thus, it was evidenced that the actions taken by general hospitals were more intrusive than the ones taken by academic since the last category is more specialized and is the last resort for COVID-19 care.

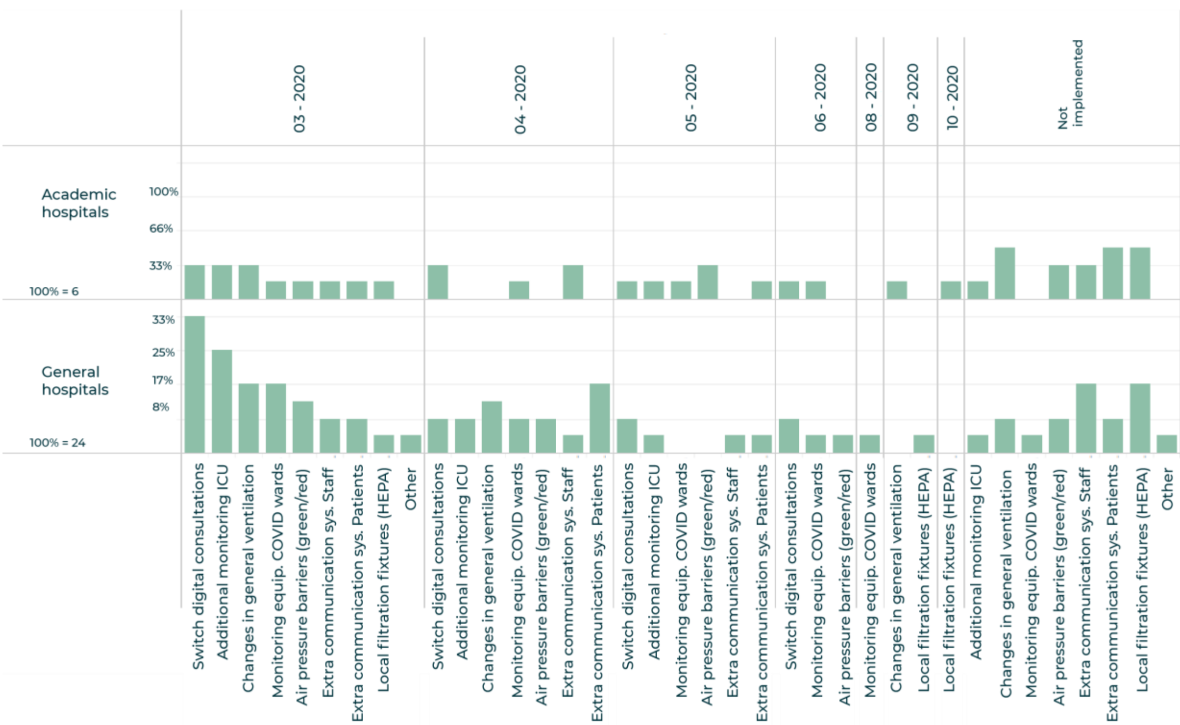

Figure 38. Technical interventions in time by type of hospital. Source: own diagram

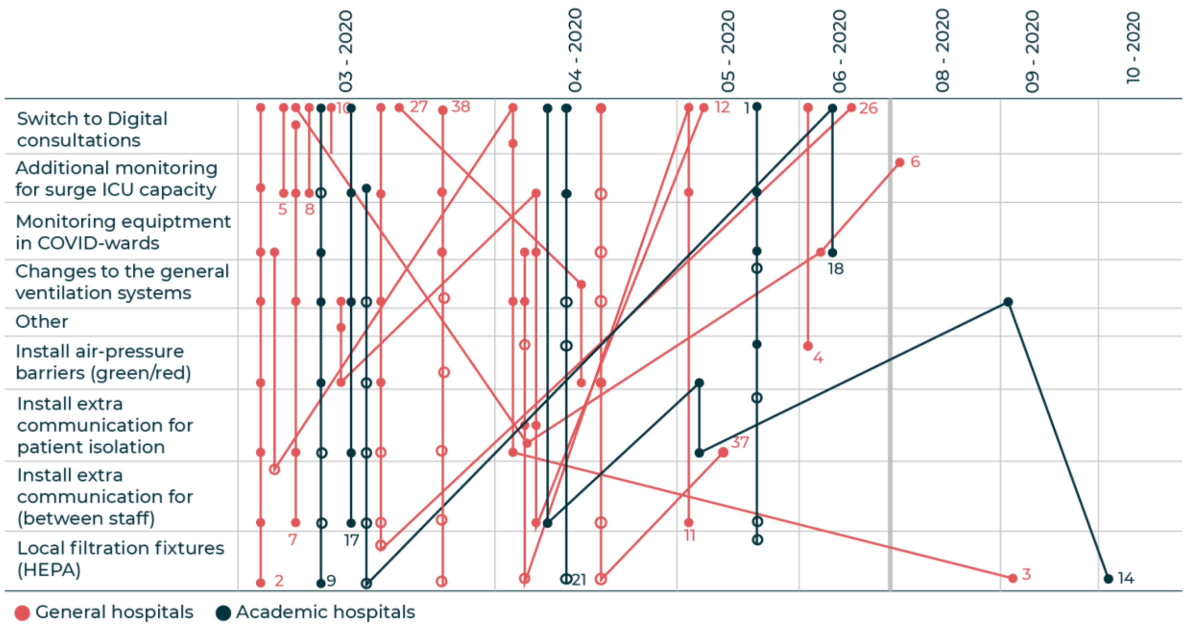

Figure 39. Timeline of technical interventions by type of hospital. Source: own diagram

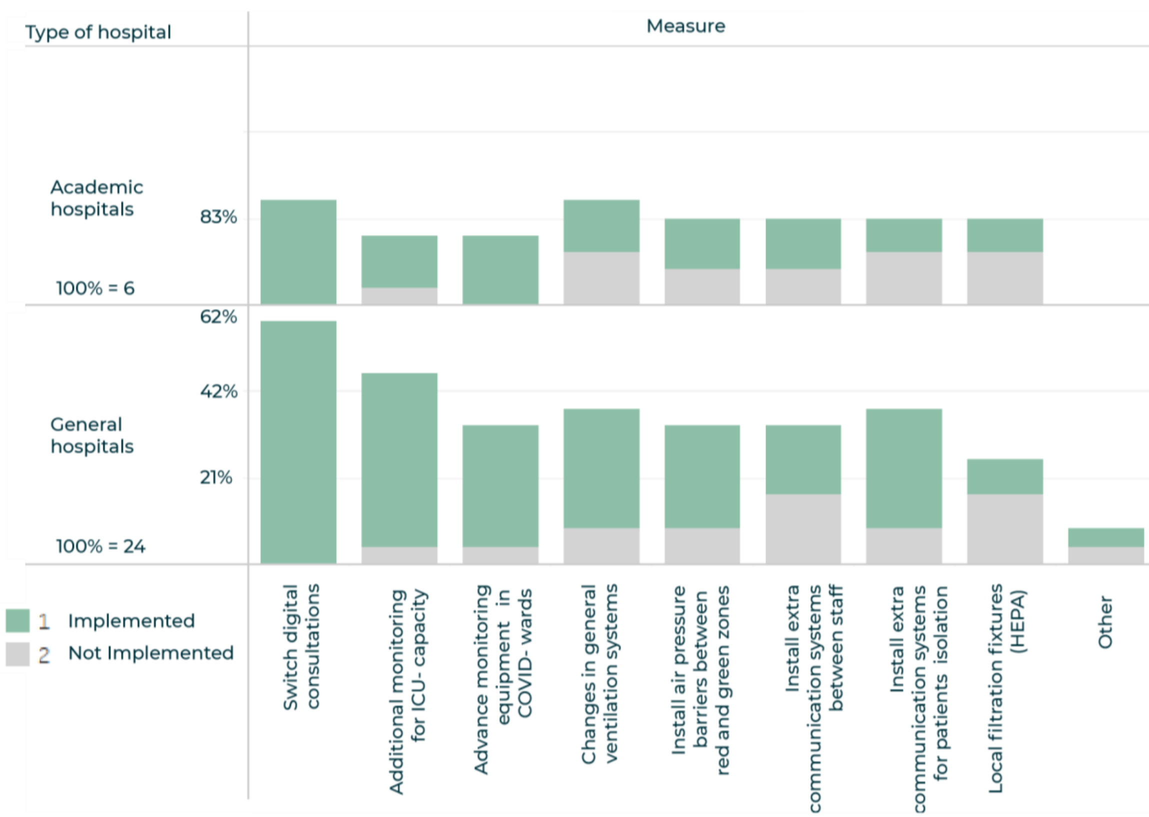

Figure 40. Technical interventions by type of hospital. Source: own diagram

Building year

As shown in figures 41 and 42, the building year is a variable that differentiates the technical interventions. Hospitals built after 2010 only registered interventions in the first wave during March and a few in April. On the other hand, the hospitals made before 2010 recorded more interventions over the different waves. Most hospitals made adjustments in the first wave during March and April, but there are also records of adjustments in May, June, August, September, and October. Thus, hospitals built before 2010 made more technical adaptations, although not all are outdated since some reported there was no need to implement all the measures.

Furthermore, as presented in figure 42, the measure most implemented by hospitals built before 2010 was the switch to digital consultations. In second place are three measures, additional monitoring for ICU capacity, advanced monitoring equipment in COVID-wards and changes in ventilation systems. The most minor enforced measures were extra communication systems between staff and local filtration fixtures (HEPA). Finally, the least implemented action for the buildings built after 2010 was installing air pressure barriers and local filtration fixtures.

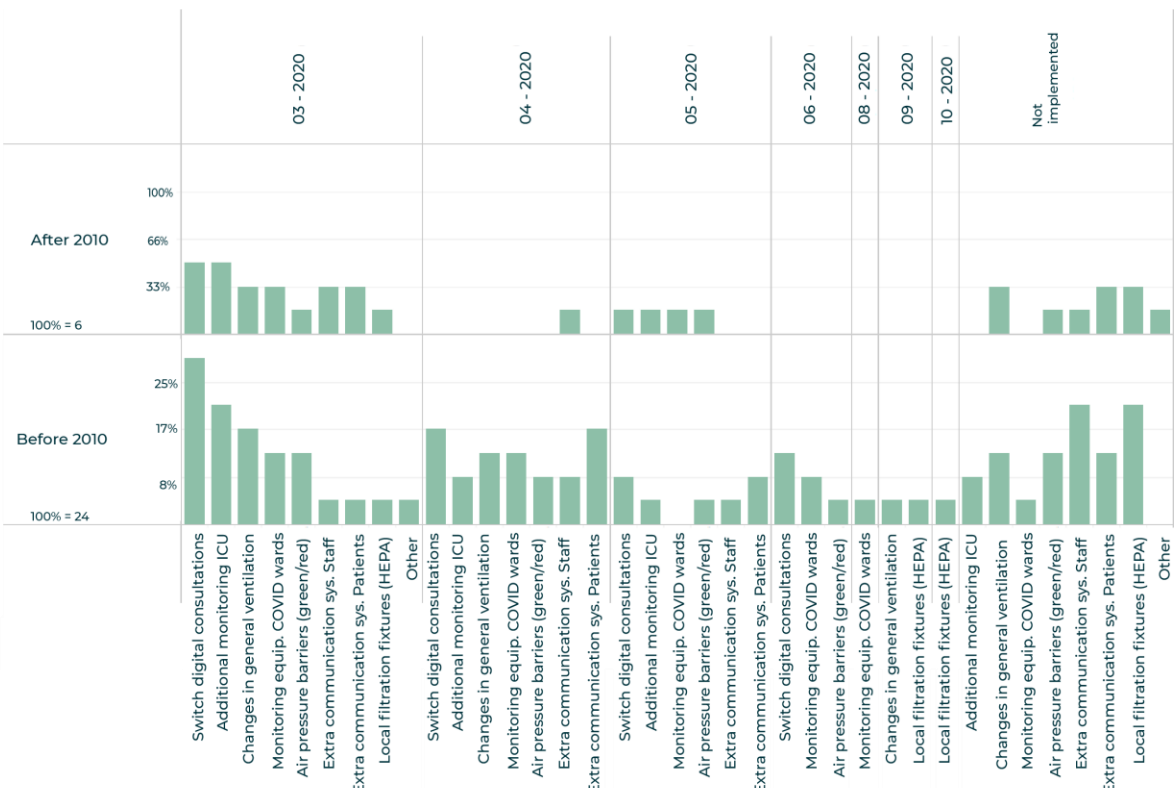

Figure 41. Technical interventions in time by building year Source: own diagram

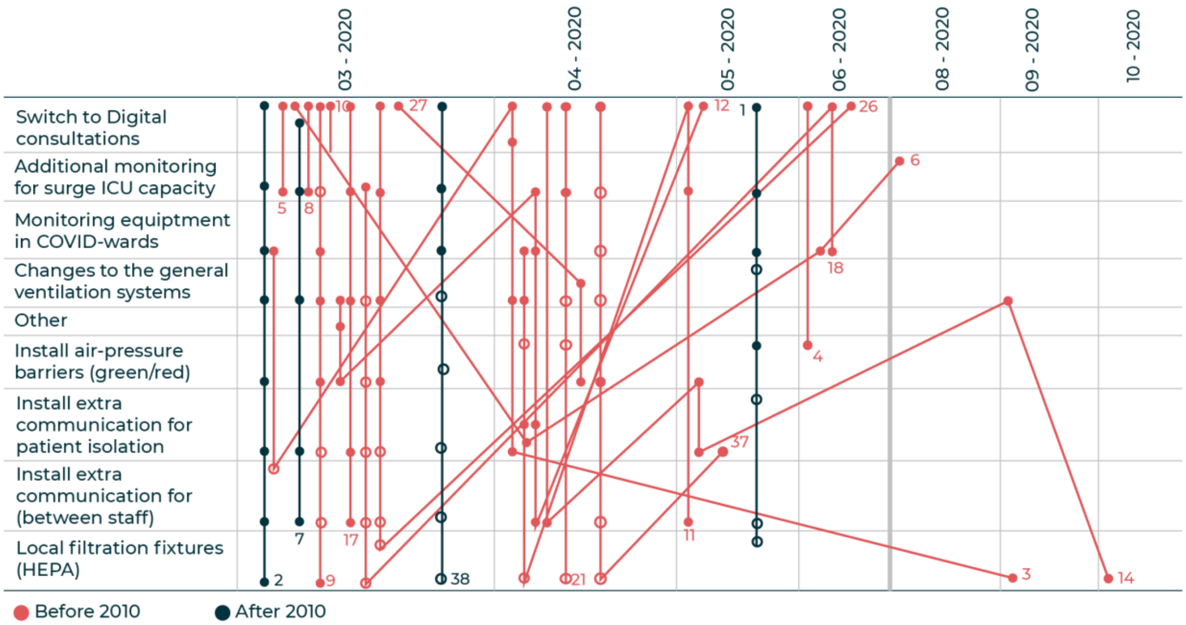

Figure 42. Timeline of technical interventions by t building year. Source: own diagram

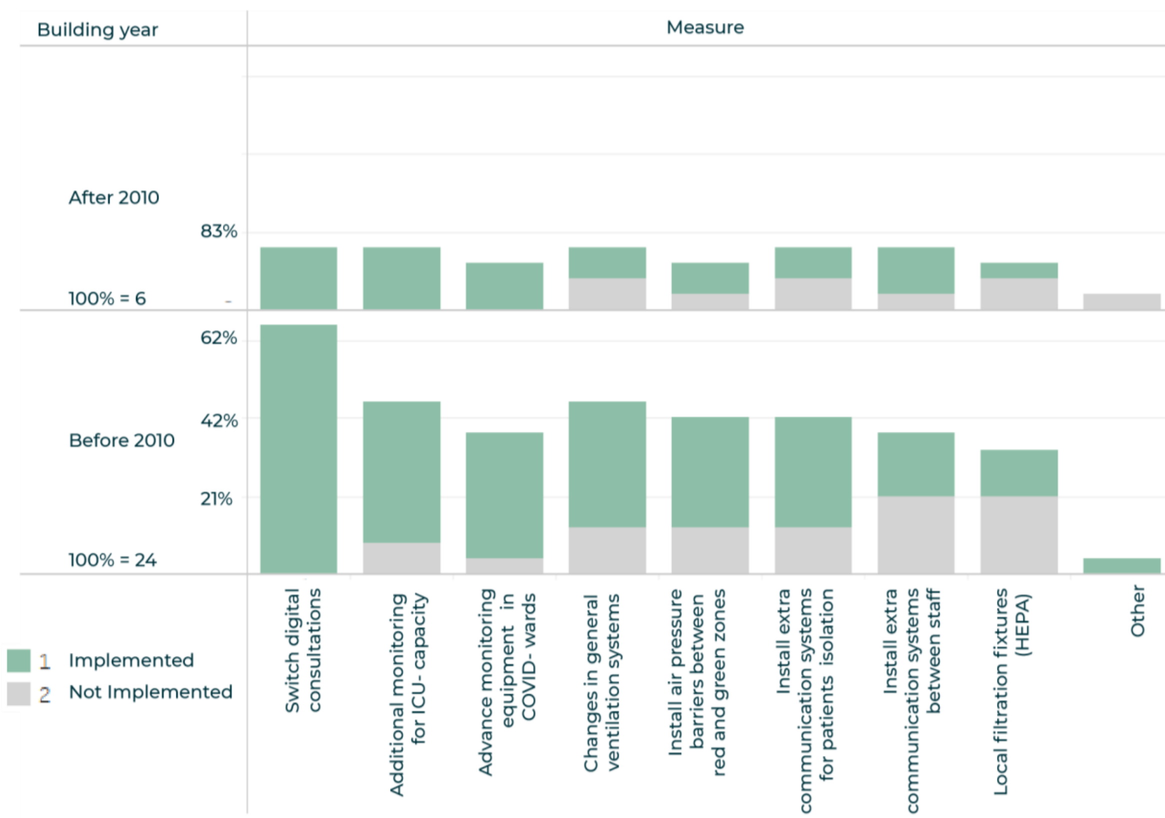

Figure 43. Technical interventions by building year. Source: own diagram

Urban density

Hospitals in low urban areas versus buildings in high urban regions are shown in figures 41 and 42. It was found that hospitals located in low, dense municipalities did the technical modifications in the first wave, mainly in March and in June. Whereas in high dense locations, hospitals did more interventions more frequent in time. Most hospitals did the changes in the first wave in March and April. Also, in May and June, many hospitals adjusted installations. One differentiation illustrated in figure 43 is that low urban hospitals did not register implementation of local filtration fixtures.

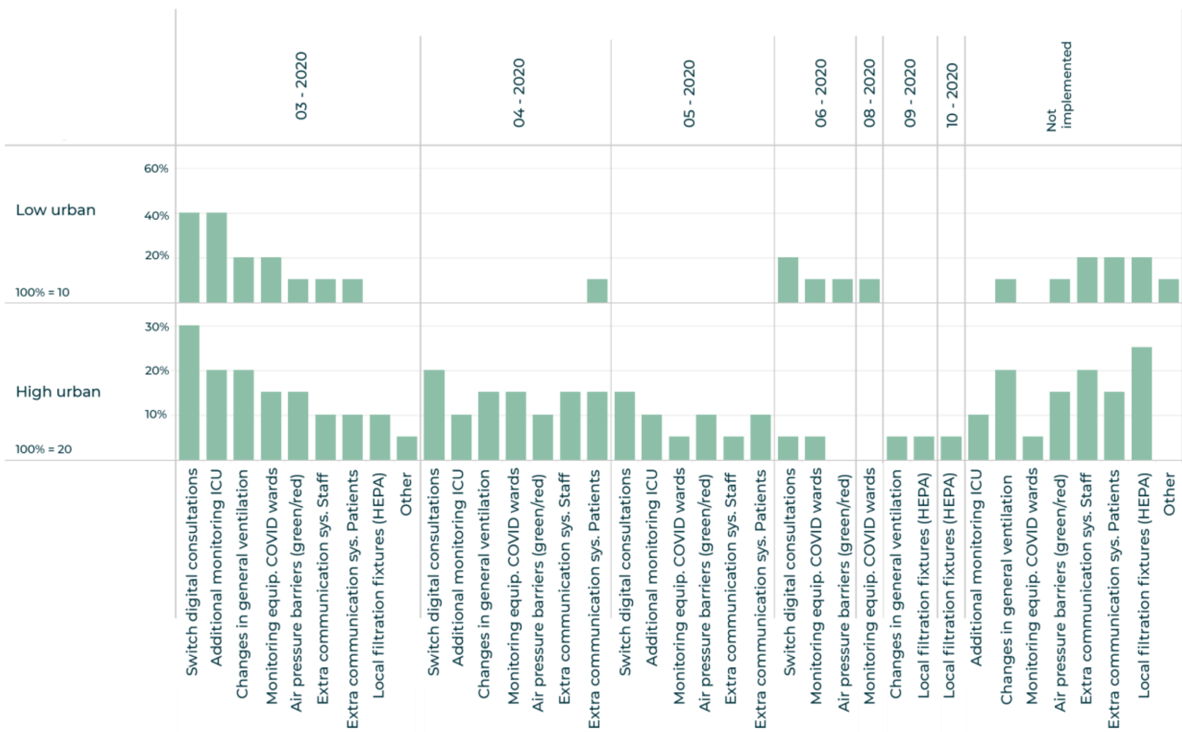

Figure 41. Technical interventions in time by urban density Source: own diagram

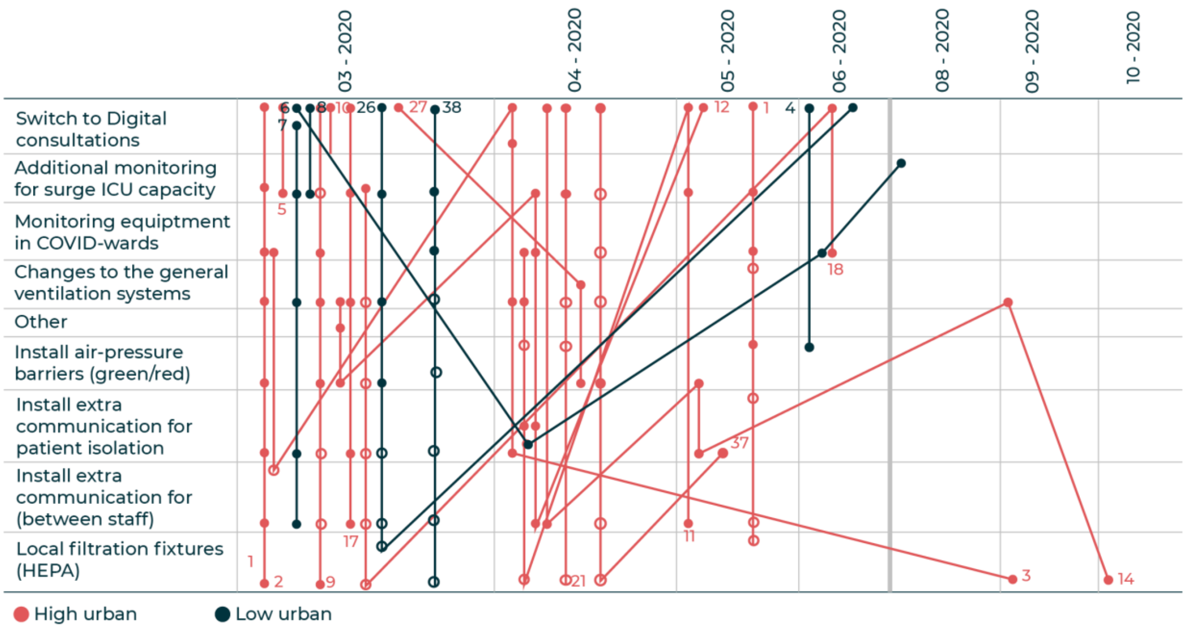

Figure 42. Timeline of technical interventions by urban density. Source: own diagram

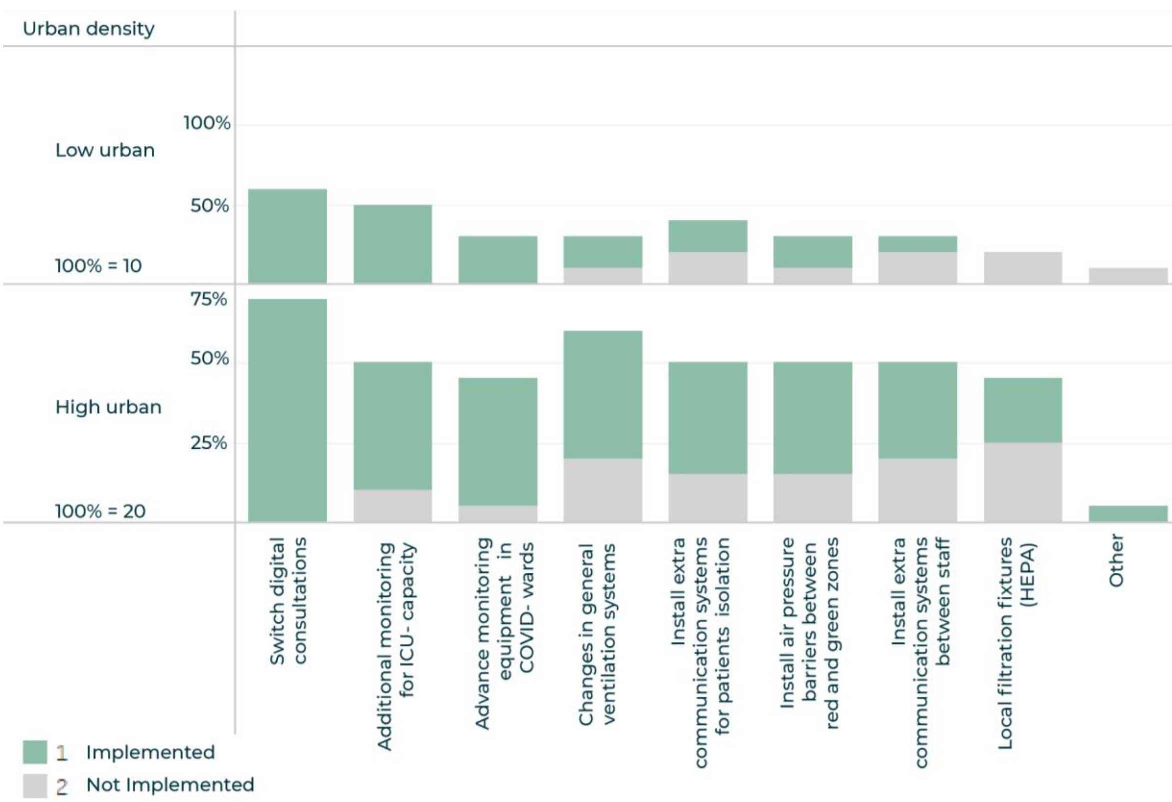

Figure 43. Technical interventions by urban density. Source: own diagram

4.2.6 Employee-focused interventions

Type of hospital

When detailing the services provided for medical staff by type of hospital, some differences can be seen in time. As graphs 38 and 39 show, academic hospitals that answered the survey implemented the services during the first and second wave, mainly in March 2020. The most implemented measures at the beginning were: 1. non-essential staff working from home, 2. information sessions for staff like live streams, 3. additional attention for mental well-being, 3. Additional free parking, 3. Childcare.

In contrast, general hospitals made service adaptations only in the first wave. March was the busiest month, but the general type took more services in April and May. In March, most hospitals did 1. non-essential staff working from home, 2. additional attention for mental well-being and 3. information sessions for staff like live streams. During May 2020, additional attention for mental well-being was the most registered service for this category.

Figure 40 illustrates that academic hospitals offered more free parking, childcare, and temporary accommodation in local hotels than general hospitals. Moreover, the general type offered more shopping services than academic.

Figure 38. Employee-focused interventions in time by type of hospital. Source: own diagram

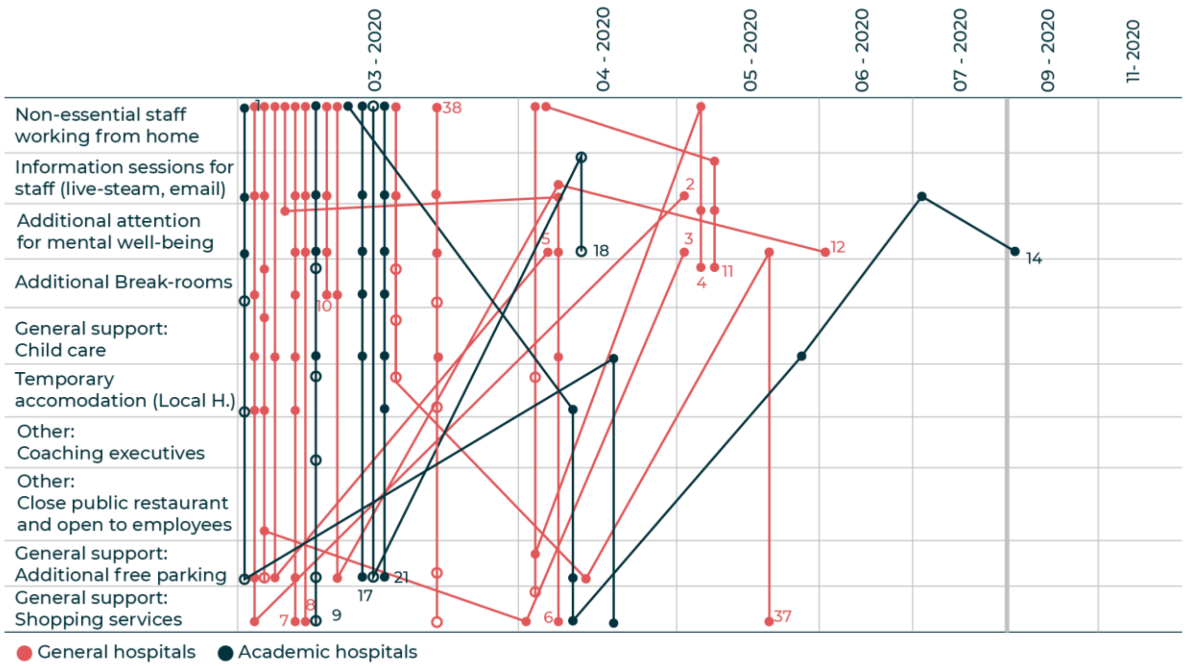

Figure 39. Timeline Employee-focused interventions by type of hospital. Source: own diagram

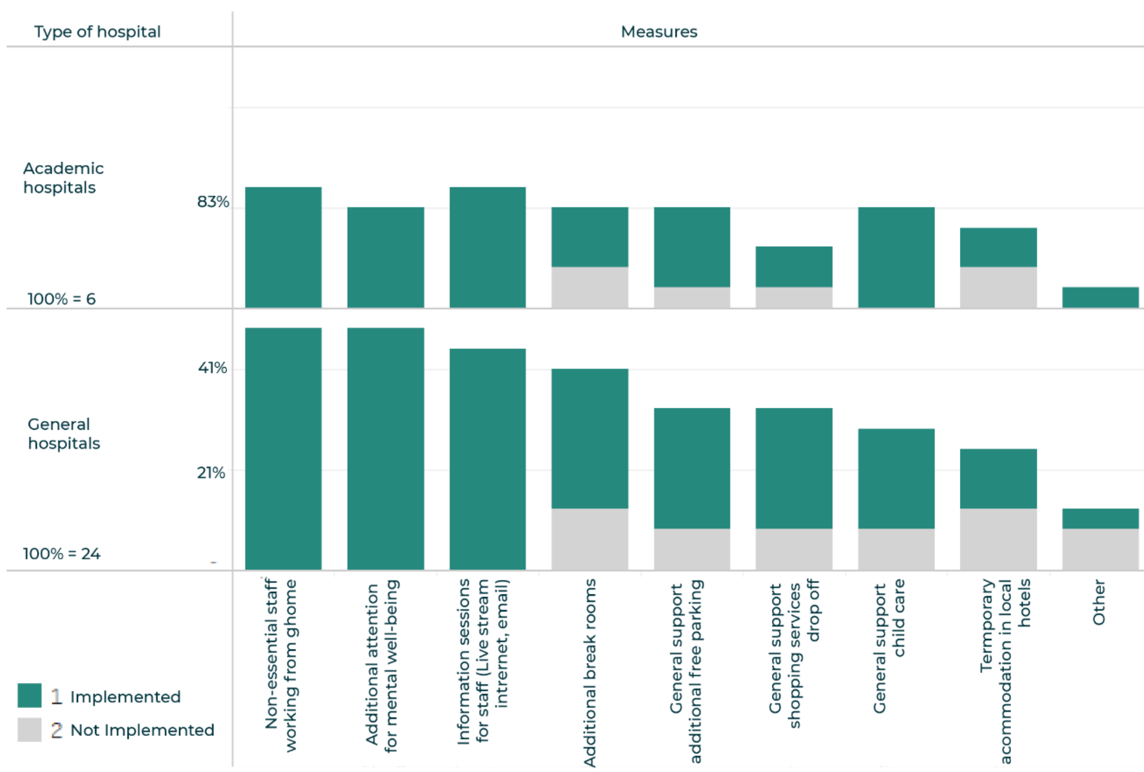

Figure 40. Employee-focused by type of hospital. Source: own diagram

Building year

Services for staff compared by building year is plotted in graphs 41 and 42. Hospitals made after 2010 took most services in the first wave of the pandemic. Most of the hospitals registered adaptations in March 2020. In April 2020 and May 2020 were provided additional attention for mental well-being. In November 2020, on the second wave, temporary accommodation was recorded.

Buildings constructed before 2020 registered a more significant number of services during the first and second wave systematically. Most hospitals adapted in March 2020, and in April and May, many services were supplied. Additionally, figure 43 shows that the least offered services by older hospitals were temporary accommodation in local hotels, shopping services and childcare.

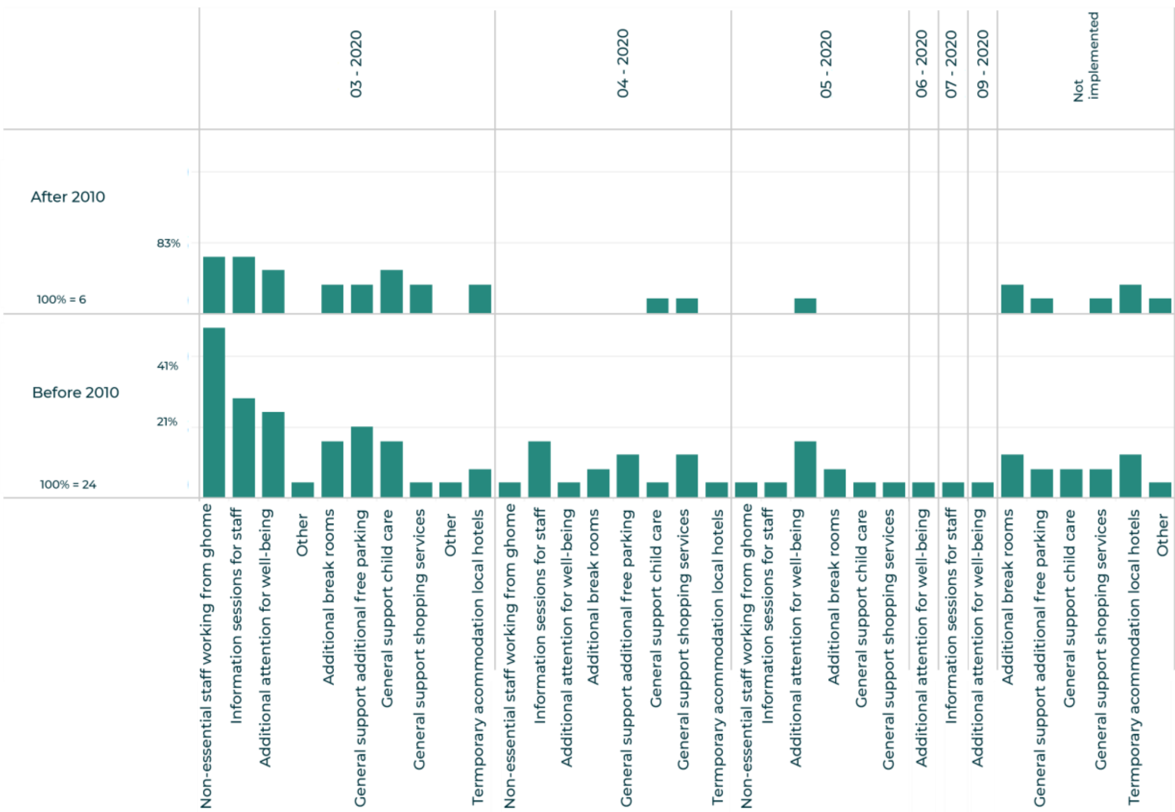

Figure 41. Employee-focused in time by building year Source: own diagram

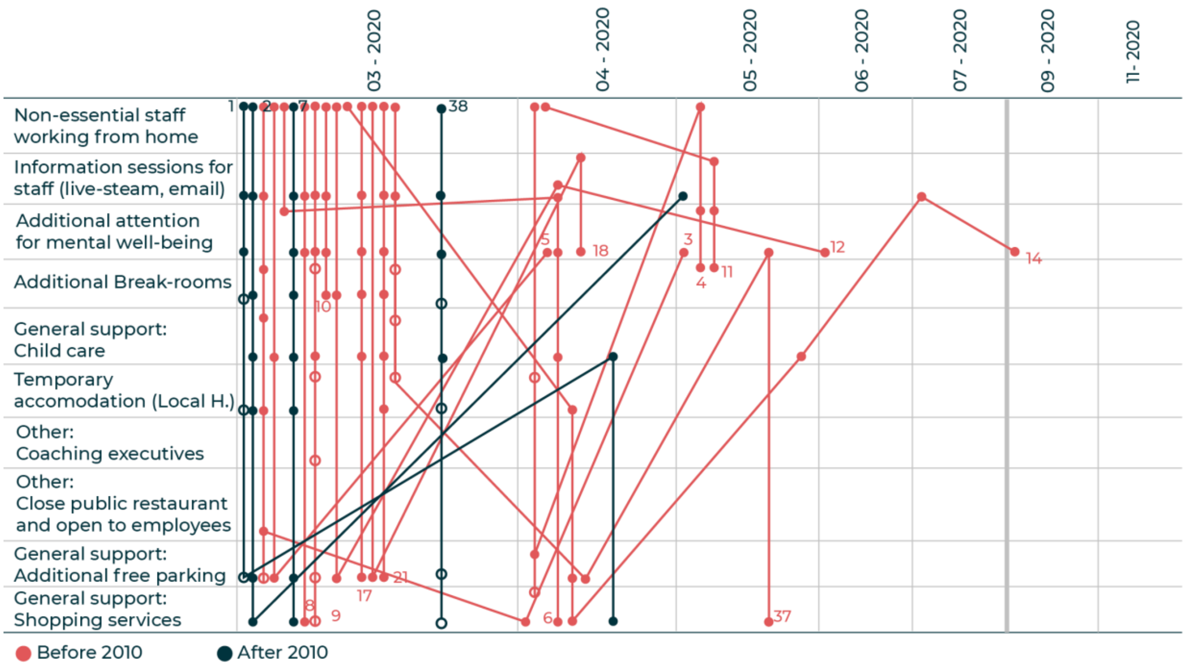

Figure 42. Timeline of technical interventions by t building year. Source: own diagram

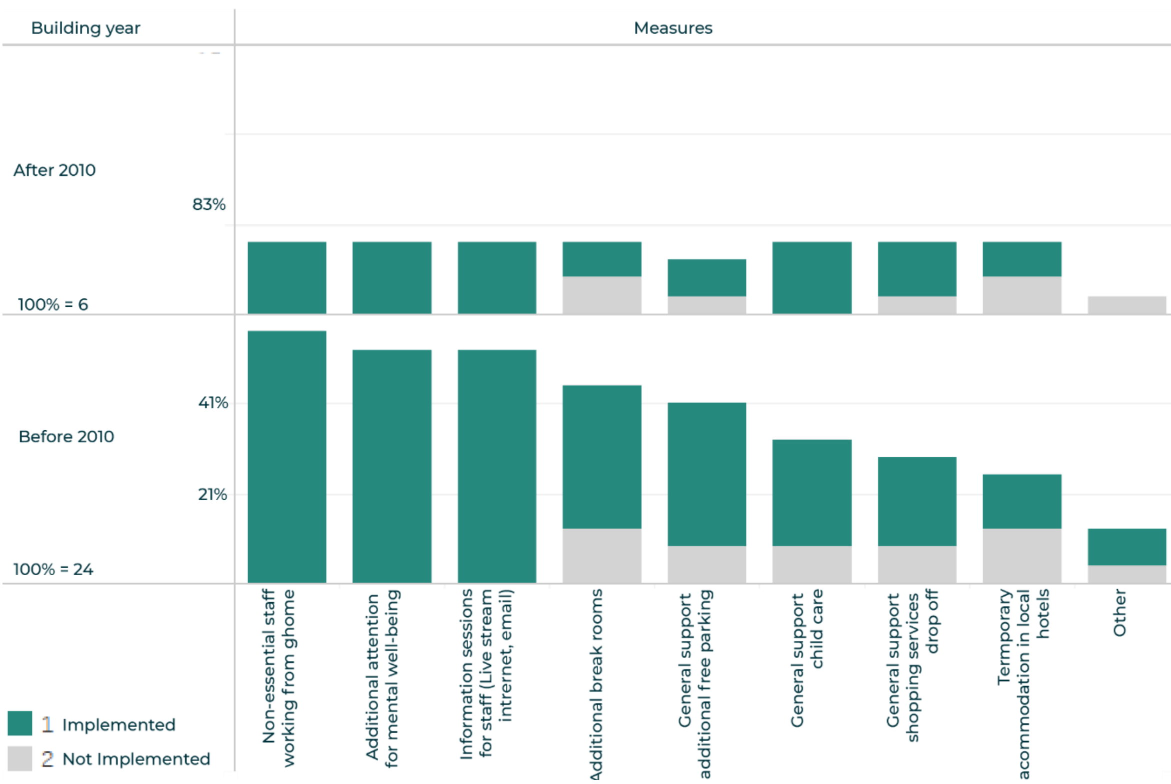

Figure 43. Technical interventions by building year. Source: own diagram

Urban density

Based on the survey responses illustrated in figures 44 and 45. Hospitals located in low urban areas only implemented services for staff during the first wave in March, April, and May. On the other hand, hospitals in high urban municipalities adapted services during the first and second wave. During March, April, and May, many services were provided compared to low urban areas. Also, in May was notorious the implementation of additional services for mental well-being.

Figure 46. shows that hospitals in high urban areas adopted additional staff services and that the least provided service was support in shopping services and temporary accommodation in local hotels. On the other hand, in low urbanity areas, more hospitals of that category implemented the drop-off.

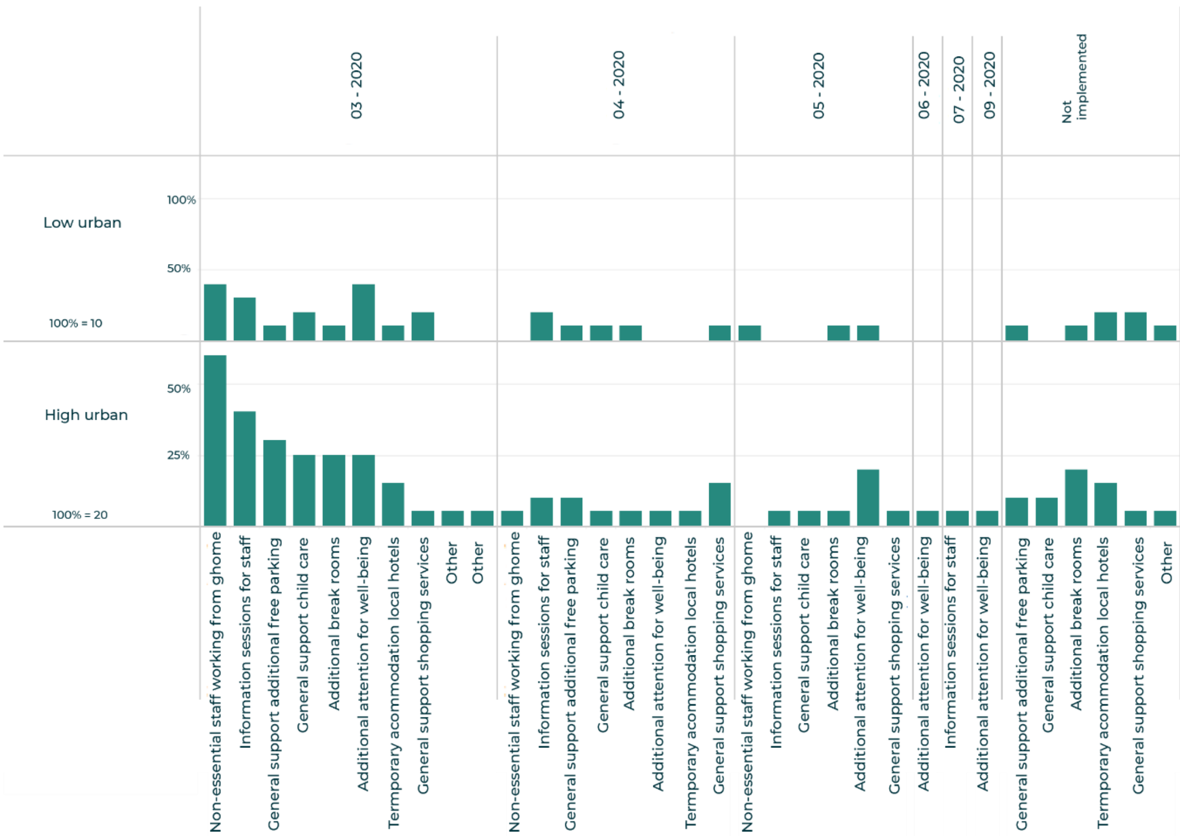

Figure 44. Employee-focused interventions in time by urban density Source: own diagram

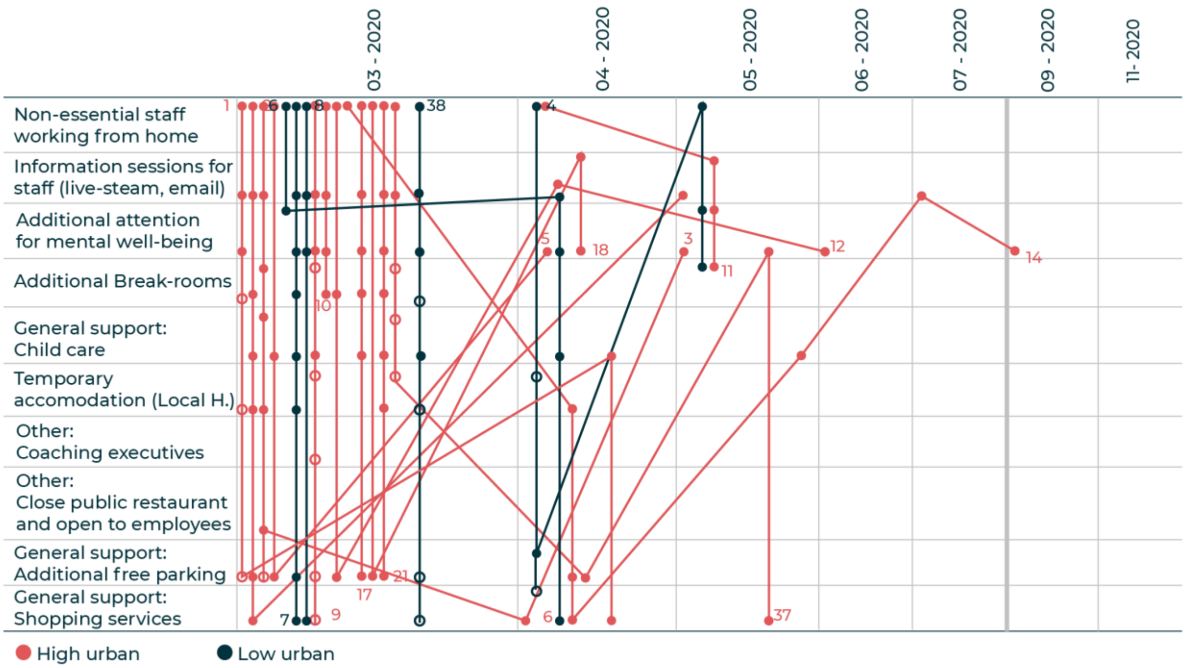

Figure 45. Timeline of Employee-focused interventions by urban density. Source: own diagram

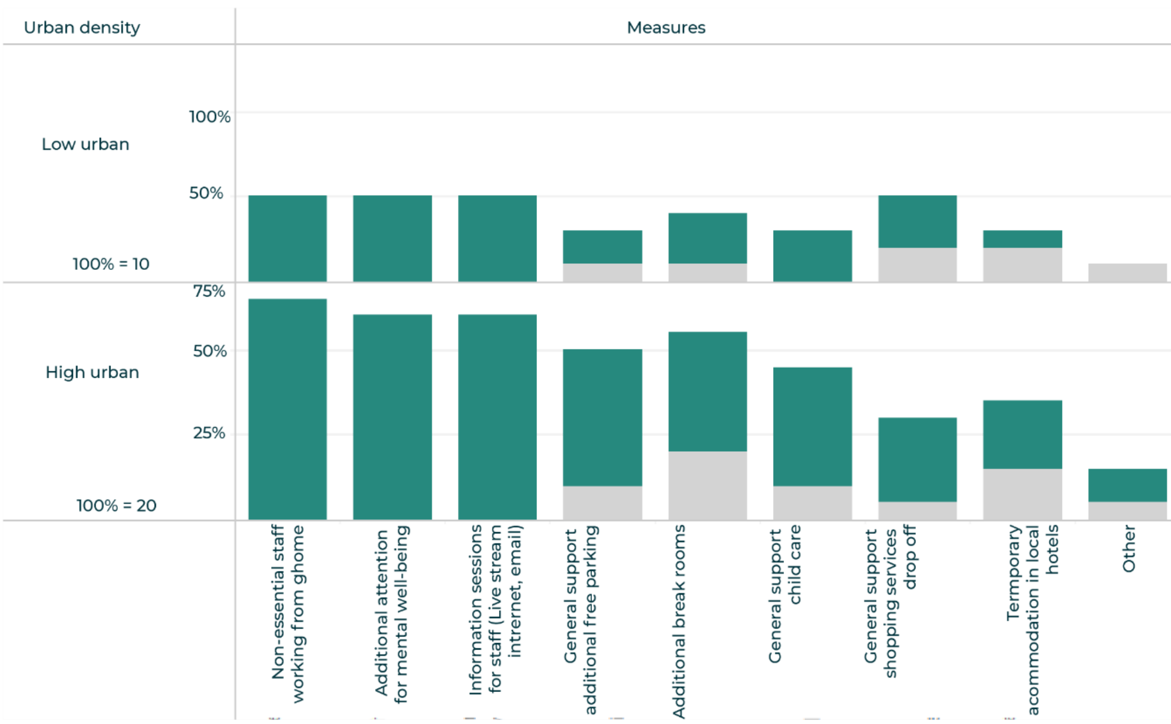

Figure 46. Employee-focused interventions by urban density. Source: own diagram

4.2.7 Summary

Table 5. Summary analysis safety measures taken during the 1st, 2nd, and 3rd wave and hospital spatial characteristics.

<table>
<tr><th></th><th>Building interventions
General top measures: Hand alcohol, segmentation wards, visual cues)</th><th>Technical interventions
General top measures: Switch to digital, additional monitoring for ICU-capacity</th><th>Employee-focused interventions
General top measures: non-essential staff working from home, additional attention for well-being and information sessions</th></tr>
<tr><td>Type of hospital</td><td>Academic
Measures did in March 2020.
Homogeneous implementation of measures by hospitals.
Did some additional modifications (screening of visitors, changes in ED)
General (more interventions)
Hospitals took more measures frequently in the three waves (Busy March, April, May).
In proportion, fewer hospitals repurposed spaces, separated entrances, and segregated flows.</td><td>Academic (more high-tech)
Most hospitals did the measures first in March and April 2020. (Few in the rest of time)
Many hospitals registered that not implemented measures.
Top measures: Switch to digital and advanced monitoring equipment.
General (more intrusive interventions)
Hospitals took more measures frequently in the first two waves (Busy March, April, May).
The top 3 measures implemented were additional monitoring for ICU and changes in the general ventilation system.</td><td>Academic (offered additional services)
Measures made in the 1st and 2nd wave.
More free parking and childcare in general.
Least provided service was shopping services and additional break rooms.
Some did not implement services.
General
Measures in 1st wave.
Hospitals took more measures frequently in March, April, May 2020
The peak of additional attention for well-being in May 2020.</td></tr>
<tr><td>Building year</td><td>Before 2010 (Excess capacity)
Hospitals took more measures frequently in the three waves (Busy March, April, May, June, August).
Fewer hospitals repurposed spaces into ICU, separated entrances, segregated of flows and visual communication.
After 2010
Hospitals took measures in the three waves. Mostly in March 2020.
In general, fewer measures than hospitals before 2010.</td><td>Before 2010 (more interventions)
Hospitals took more measures frequently in the 1st and 2nd wave. (Busy March, April, May, June, Aug, Sep).
Many hospitals registered that did not implement measures.
Top measures: Switch to digital, additional monitoring, changes in ventilation systems.
After 2010 (also did interventions)
Hospitals took measures in the 1st wave (only March and April).
The most minor enforced measures were the installation of air pressure barriers, together with local filtration fixtures.</td><td>Before 2010
Measures in 1stand. 2nd wave.
A significant number of services, more frequent (busy March, April, May)
Top services: Additional attention for well-being, info sessions, no-essential staff working from home.
Less: Temporary accommodation, drop-off
After 2010
Services mainly in 1st wave.
April, May only mental well-being.
Less drop-off, fewer additional break rooms</td></tr>
</table>

	Building interventions General top measures: Hand alcohol, segmentation wards, visual cues)	**Technical interventions** General top measures: Switch to digital, additional monitoring for ICU-capacity	**Employee-focused interventions** General top measures: non-essential staff working from home, additional attention for well-being and information sessions
Urban density	*Low urban* • Measures in 1st and 3rd wave. • Less segregation of flows and repurpose of spaces.	*Low urban* • Measures in 1st and 2nd wave. • Adaptations mainly in March and June • Less enforced measure was installing communication systems between staff.	*Low urban (More shopping services)* • Measures in 1st wave. • Shopping services and additional break rooms were services more delivered than in high urban. • Top measures both: non-essential staff working from home, additional attention for well-being and information sessions
	High urban (busier) • Measures in 1st,2nd, and 3rd wave • More measures more frequent. • Busy March and April 2020. • Some hospitals took additional measures.	*High urban (more interventions)* • Measures in 1st and 2nd, wave. • More measures more frequent. • Extra interventions. • Some hospitals did not implement all measures. • Top measure: Switch to digital consultation	*High urban (offered more services)* • Measures in 1st and 2nd, wave. • March, April and May a more significant number of services were provided compared to low urban. • Adopted extra services for staff. (coaching & restaurant) • Less implemented was shopping services.

After the analysis, it was found that there were some top sub-interventions implemented by most of the respondents. Regarding building interventions, the most enforced measure was the segmentation of wards after hand alcohol. The technical was the switch to digital consultations, and in the category of services for staff, the most implemented was non-essential staff working from home.

Table 4 shows that the spatial characteristics of hospitals can differentiate some of the measures taken during the three waves of the pandemic. General hospitals took the safety measures more constant in time, while most academics did the building interventions before, primarily made in the first wave (March). Furthermore, less intrusive technical installations needed to be done compared to the general hospitals. Since academic hospitals are more specialized, they need to keep free capacity if specific procedures are required. Regarding adaptations in staff services, in proportion, academic offered more parking services and childcare for the healthcare workers. General hospitals took more overflow of covid patients since academic type are the last resort. Thus, more building and technical interventions needed to be done to offer more capacity.

Regarding the building year, hospitals built before 2010 took more safety measures in general. However, it was visible that older buildings did less repurpose spaces into ICU capacity, separation of entrances and segregation of flows. Older buildings were not affected by the 2008 policy in which the surface of facilities was limited, and more compact hospitals arise. Buildings built before 2010 had more space to accommodate the surging demand; in some cases, some available ICUs were not in use due to the lack of staff. Furthermore, it was also evident that hospitals built before 2010 made more intrusive changes in general ventilation systems and more technical modifications than new buildings. Regarding services for staff, older facilities recorded in proportion fewer services of accommodation for staff in local hotels.

Finally, concerning urbanity, hospitals located in low-density areas appeared less busy than building in high-density areas. Thus, buildings with higher urbanity did more spatial, technical modifications and offered services for the staff to a greater extent, including some extra services like a restaurant for employees and coaching sessions. In contrast, low urban hospitals implemented more minor services in time but adopted more shopping services than urban hospitals.

4.3 Results from the interviews

Three interviews with academic hospitals have been carried out. The findings from the interviews were categorized into five overarching themes, primarily the Dutch context explained in chapter 2.2, and the four themes defined previously as the main topics for the interview protocol; 1. **Context crisis preparation**, 2. **Strategies & policies of the emergency response**, 3. **Changes in logistics**, and 4. **Long term perspective**. A hierarchically ordered structure of themes and subthemes which in turn are used as codes, is developed. The relations between the codes are depicted graphically in figure 47; With this structure, it becomes possible to differentiate incidents in the text passages assigning the codes. In addition, some descriptive codes were included to classify the findings. For example, the results were coded in the safety measures (building interventions, technical interventions, and employee focused interventions). Additionally, some other codes were defined to group the lessons learned, difficulties and changes during the crisis experience. The interview transcripts are confidential and will be submitted independently to the academic tutors.

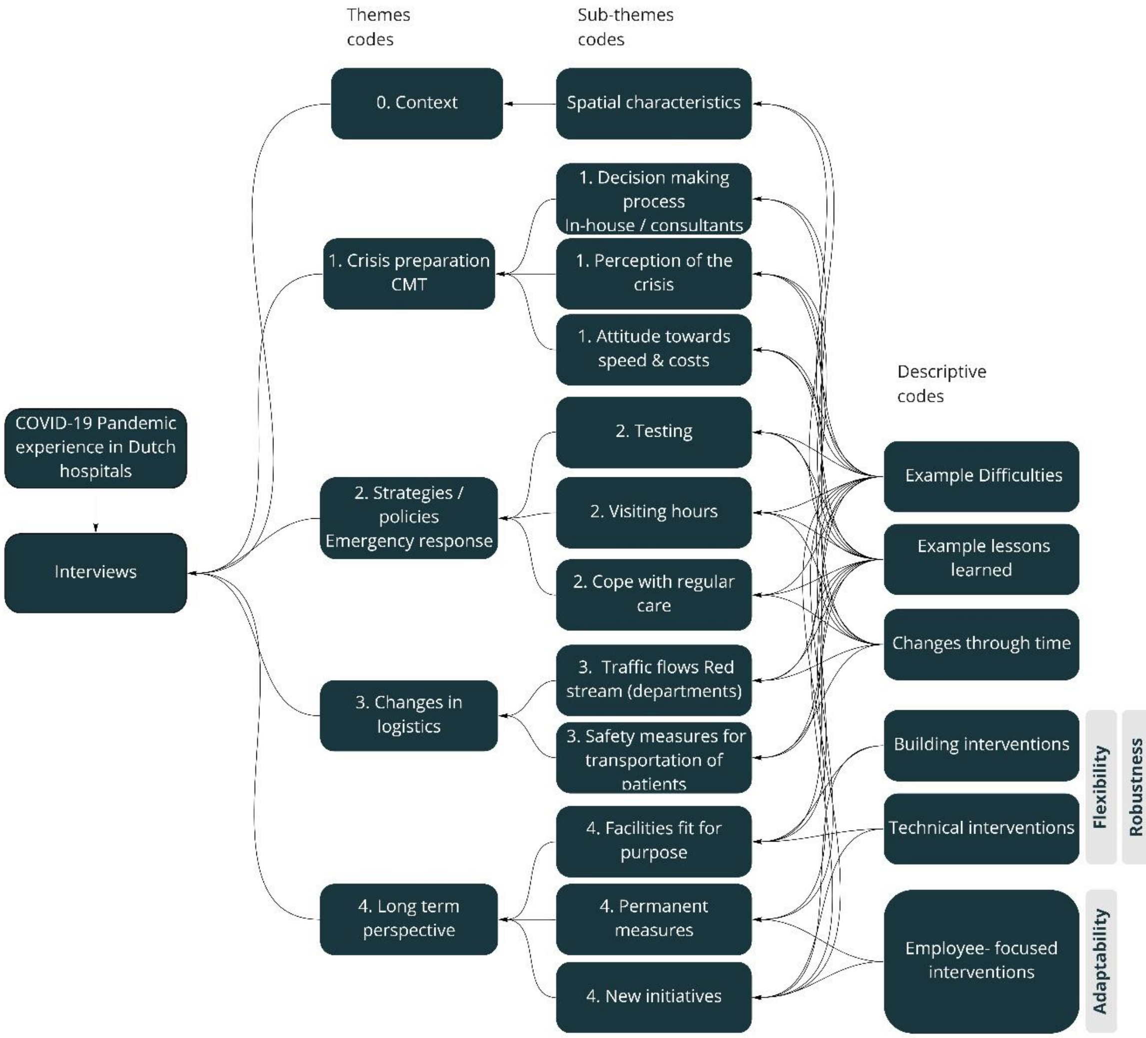

Figure 47. Code categorization and relations. Source: Own diagram

4.4 Findings for research question 2

Based on the pandemic experience, what interventions should be considered in hospital design to future-proof projects to virus-like covid-19?

The information obtained from the interviews is complemented with the outcomes from the last part of the survey. For the final section of the questionnaire, the participants were asked to reflect on the pandemic experience and mention which measures should be included in a hypothetical hospital renovation design.

After a qualitative analysis, the main findings can be classified into building, technical, and employee-focused measures.

4.4.1 Building interventions

One of the main lessons from the interviews was that there might be future infections related to lungs and respiratory problems. With the growing population and the characteristics of infectious diseases, there is a good chance that lung diseases appear again. Hence, for being more prepared for lung-related demands, future hospital design should plan for surge capacity, not only in terms of ICUs but also in the nursing wards.

As occurred during the second and third pandemic wave, the bottleneck was no longer the number of ICUs. Instead, the issues turned out in the nursing wards, where most patients were treated with oxygen provision. Future hospital design should consider the number of "ventilation beds" available with artificial respiration mechanisms like Opti flow ventilation. Medium care could help contain a future possible surge demand like occurred in the COVID-19 pandemic crisis. Thus, hospitals are evaluating strategies to increase capacity through versatile and scalable spaces, like planning single patient rooms able to accommodate two patients when necessary.

"In the wards, we have now two-person room and single-person rooms, and the idea in the future is that we use single-person rooms for one person and when we have a crisis, we could accommodate another person".

Nevertheless, some hospitals presented difficulties during the pandemic response when providing shared oxygen in the nursing wards because the building had insufficient overall capacity. Hence, the accommodation strategies should be convertible in terms of infrastructure and installations. Particular attention should be given to installations like ICT, but awareness about the building's overall oxygen and power supply capacity should be given. The backbone infrastructure should be designed in such a way as to avoid failures during the hospital lifetime.

Another finding related to the building configuration was multipurpose spaces are helpful in a crisis time. Hospitals find very convenient spaces like parking and outdoor areas to install pop-up services or temporary structures directly connected to the building. Furthermore, inside the hospital, there also should be the possibility to store or install additional equipment if necessary.

"There was a lot of equipment installed in the crisis, so they moved out offices and got in the equipment. Another thing is around our hospital, we have space, most of the gardens or parking lots, and we claim them when we have to put on tents."

Finally, the option to isolate infected patients within the building is essential to manage infectious disease. Thus, the building "red" and "green areas should be considered in future developments.

"You have to be able to separate some part of your building for infected patients. Some part without too much traffic around an isolated part of the hospital."

4.4.2 Technical interventions

It was found that the switch to digital consultations was one of the measures most implemented by Dutch hospitals during the pandemic. Moreover, with the interviews became clear that telehealth will continue in the long-term run of healthcare.

"The video consultations have increased ten times after the crisis, and probably be something that continues to be there after COVID-19".

Digital examinations have become a trend, and future hospital design should consider the impact in terms of space and infrastructure for virtual sessions. Some hospitals are contemplating arranging rooms for digital care inside hospital facilities.

"We think about making a small space is only for digital communication."

Moreover, as mentioned in section 2.3 of the report, the outpatient department holds the fastest-growing group of patients in normal circumstances and represents a significant traffic flow. Virtual consultation could help increase the system's capacity considering the growing group of patients that would require primary care in the future. Furthermore, it was found that the aim is to decrease the number of visitors to the building by implementing more digital care.

"The goal for the outpatient department is to reduce 50% of the visits to the hospital and replace them by video consulting."

Future hospitals should consider the impact of digital consultations in the design, especially in the outpatient department where primary care is delivered. Spaces for virtual consultations should be arranged in which internet connectivity with high-speed capabilities are necessary to support the telehealth experience (Center for Advanced Design Research and Evaluation CADRE, 2020). Nevertheless, the surface for the waiting areas should not be reduced considering that in a future respiratory contagious disease, the area should be enough to keep a safe distance between patients.

It should be taken into consideration that digital communication could be an issue for the ageing population and the elderly with underlying health conditions that often go to diagnosis and control. Additionally, not all services could be effectively moved to a virtual platform. Therefore, understanding which functions could be delivered virtually and establishing clear guidance is essential to evaluate whether telehealth, in-person visit, or a hybrid method are more appropriate. Furthermore, the experience during the virtual consultation should be enhanced so that the relationship between patients and physicians is felt as personal interaction and a virtual visit is a worthy substitute for the in-person visits (Center for Advanced Design Research and Evaluation CADRE, 2020).

During the interview, it was discussed if the reduction of 50% of the in-person visits would be possible to achieve. Not all the inhabitants have accessibility to technological tools, and virtual talks could be difficult for some patients. Therefore, access to technology and the internet must be distributed equitably to all population (Center for Advanced Design Research and Evaluation CADRE, 2020).

Another finding related to technical interventions is the separation of airflows. For example, some hospitals had to install temporary air pressure barriers to compartmentalize the ventilation from infected and non-infected patients during the COVID-19 crisis.

"Ventilation adjustments can be made more permanently, so we don't have to improvise things".

During the crisis, air pressure barriers were made since the beginning of the pandemic and was an adaptation registered by different groups of hospitals. In some cases, the ventilation system is integrated in the whole building, and it is not easy to divide the airflow within a department. *"In the future, what is essential is to create an isolation ward inside the ICU department, instead of only create isolation rooms".* Thus, since the design stage, the separation of airflows could be considered in the units, so the ventilation from infected patients is already independent in another infectious disease.

"The units can be divided quite easily by closing doors, but in the ventilation, it's a little bit difficult because it's all integrated and if you have to wonder, have special separated ventilation for these units, you have to adjust it in the structural."

Modifications that affect the structural, technical system might not be financially feasible for a building renovation. In another infectious disease, hospitals without the possibility to categorize airflows might need to arrange a temporary solution again. Future hospital design could consider separating the ventilation system in the units early before construction to avoid structural changes during the building lifetime. Separation of ventilation

4.4.3 Employee-focused interventions

Regarding employee-focused interventions, non-essential staff working from home was the most implemented measure during the pandemic response. After the interviews, it was found that the COVID-19 pandemic has accelerated remote working, and it will continue being implemented on a long-term basis.

"I think it will be a cultural change, and it was already going on. But it has been speeded up with the pandemic."

Future hospital design should acknowledge that non-patient related staff that used to go to the healthcare facilities five days per week before the pandemic will continue working from home regularly after the crisis. Thus, home-office might imply a reduction in the use of workplaces. Nevertheless, space for offices could be used for other functions like storage or additional equipment.

"I think 80 or 90% of the people are working at home and they will stay at home. Perhaps it will be 70% but not 10% as it used to be before the pandemic. A lot of people like me will be working, I think three to the max in hospital, just because to be there because technically I don't need it."

Another finding suggested in the interviews was the lack of functional spaces in the areas that offer services for the employees, especially in hospitals built before 2010. For example, Breakrooms and meeting rooms for employees should include digital functionalities in terms of communication to enable virtual services to be part of the daily basis of healthcare workers.

"All the traditional staffrooms will be rebuilt and redecorated to video conferencing room." "I think the meeting rooms will have far more better video facilities than they have now; in general, our ICT system of meeting rooms is not suited for video conferencing."

Furthermore, one of the main findings of this research is that staff is a core asset for hospitals, and the organizations should take care of the healthcare workers by offering services that support their well-being. Hence, future hospital design should consider enough breakrooms for relaxation and restoring staff after long demanding periods, such as the COVID-19 pandemic. The healthcare system is heavily dependent on patient-related employees and, therefore, the resiliency of the overall organization.

4.4.4 Summary

Table 6. Findings survey summary

Flexibility and robustness		Adaptability
Building interventions	Technical interventions	Employee-focused interventions
• The number of "ventilation beds" in nursing wards might help respond to a future crisis of respiratory disease. • Surge strategies through versatile, convertible, and scalable nursing wards could help in a future emergency response. • The infrastructure for oxygen and power supply should also be geared to high demand.	• Digital consultations might increase in the future. • Spaces for virtual communication should be arranged (internet connectivity with high-speed capabilities are necessary to support the telehealth experience) • The surface for the waiting areas should not be reduced considering that in a future respiratory contagious disease. (Keep safety distance) • Virtual consultation rooms might help increase the capacity of the system.	• Non-patient related staff might continue working from home regularly. • The use of working spaces might reduce in the future, but space could be used for other purposes in a future surge event.
• Availability of multipurpose spaces inside and outside the hospital is desirable to arrange temporary structures for storage or equipment in a future crisis. • Possibility to differentiate infected from non-infected areas.	• In some hospitals, the ventilation system is integrated in the whole building, and it is not possible to divide the airflow between infected and non-infected within a unit. Separating the ventilation system, together with the traffic flows and functions of spaces since the design stage, might help respond quickly to an infectious disease avoiding improvisation or structural changes during the building lifetime.	• Digital functionalities in breakrooms and meeting rooms for staff should be considered in future renovations and future developments.

05
Conclusion, discussion & recommendations

5. Conclusion

This research aimed to gain insight into the COVID-19 pandemic experience by investigating how hospitals performed and managed the different phases of the virus. For this purpose, the following research questions were determined: 1. *What is the relationship between the spatial characteristics of existing hospitals in the Netherlands and the safety measures taken by them during the different phases of the COVID-19 pandemic?* 2. *Based on the pandemic experience, what interventions should be considered in hospital design to future-proof projects to virus-like covid-19?*

This investigation is a practice-based study focused on the aspect of the built environment. The conceptual model in figure 48 illustrates the different challenges of hospital design evoked by the COVID-19 pandemic and shows graphically the various elements that should be considered for having resilient healthcare systems able to respond and recover from a possible crisis. The first question is related to the left part of the conceptual model. The second question is related to resilience in future hospital design and therefore is attached to the right part of the model.

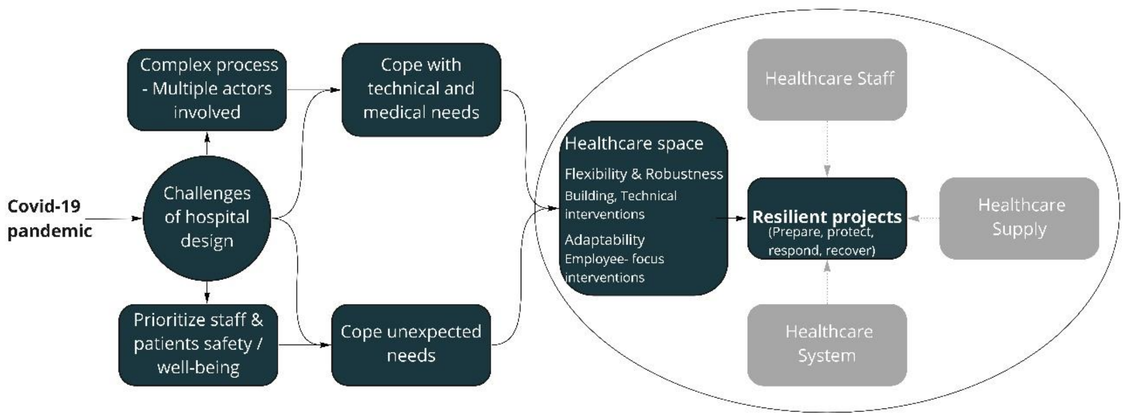

Figure 48. Conceptual model. Source: Own diagram

A qualitative approach was used to develop the research, which target group was facility and real estate managers of hospitals in the Netherlands. A survey was the starting point to collect data about the working practices during the pandemic, and the different interventions made to the healthcare facilities to respond to the surging demand for covid-care. Later, complementary information about the crisis overview, decision-making process, and future facilities perspective was collected through in-depth interviews with selected respondents that previously answered the questionnaire.

Contextual findings indicate that even though the COVID-19 pandemic has been one of the most challenging situations for the healthcare system (Ramboll, 2021; Capolongo et al., 2020), Dutch hospitals are qualified for disasters and big events. The RIVM and the GGD provided national guidance to coordinate the crisis response by hospitals in the country. Each organization had a Crisis Management Team (CMT) in charge of taking the decisions necessary to provide COVID-

19 care. Based on the interviews, the decision-making process was medically led; there was not much debate or discussion of what needed to be done. Costs were not an issue or part of the decisions made. As a result, nationwide cooperation occurred, and patients were transported all over the country to help each other manage the situation.

Furthermore, Dutch hospitals felt well prepared for the different waves of the crisis. After the first wave, where most of the building, technical, and employee-focused interventions were made to cope with the surging demand, the rating in preparedness registered in the questionnaire increased over time. Before the outbreak, hospitals had to meet complex and fast-evolving technological and medical needs related to contagious diseases (RIBA, 2020; Ramboll, 2021).

For the first research question, it was found that there were some top measures implemented by most of the hospitals. Segmentation of wards, switch to digital consultations, and non-essential staff working from home were the most implemented measures during the pandemic.

Moreover, it was found that the spatial characteristics studied in this research differentiate the building, technical and employee-focused measures taken by hospitals over the three waves of the pandemic. Regarding the hospital type, it can be concluded that the overflow of COVID-19 care lies more on the general type since the university hospitals are the last resort. Academic hospitals can be seen as frontrunners during the pandemic response; most implemented the building and technical measures first in time. Also, university hospitals offered in proportion more services for staff like more free parking and childcare. On the other hand, general hospitals were busier and needed to adapt and improve their facilities by implementing more changes in the three waves. Besides switching to digital consultations and advanced monitoring for surge ICU-capacity, the top technical measures were changes in general ventilation system for general hospitals, whereas for academic was a less intrusive change related to the installation of monitoring equipment for covid-wards. General hospitals needed to provide special attention to the mental well-being of staff to a greater extent due to the prolonged and demanding situation. Hence, additional services for staff and enough breakrooms for staff recovery could support a future crisis.

The second spatial characteristic analyzed was the building year. It was found that the year of construction also differentiates the measures taken by hospitals during the pandemic. Hospitals built before 2010 were not affected by the government policy of 2008. The building measures less taken by older hospitals were the repurpose spaces, the separation of entrances and segregation of flows. Findings suggested that pre-2010 hospitals have an excess capacity that helped quickly scale up the number of ICUs during the first wave. *"We have the luck that we have two big ICU units, and because of understaffing, one unit is almost always empty, but they could be opened very quickly".*

In contrast, buildings constructed after 2010 resulted in more compact hospitals. Post-2010 buildings needed to implement more measures related to flexibility, like repurpose of spaces, separation of entrances and segregation of flows. Thus, it can be concluded that flexibility was an essential characteristic during the pandemic response for the newest hospitals. Moreover, it was found that buildings built before 2010 made more changes in ventilation systems. In general, more technical modifications than new buildings. Furthermore, older buildings recorded in proportion fewer accommodation services for staff in local hotels regarding staff services.

Finally, the third spatial characteristic of urban density also differentiated the measures taken in the three waves of the pandemic. Hospitals located in high urban areas were busier and therefore implemented more measures frequent over time. One main finding was that hospitals in high urban municipalities offered extra services for staff like restaurant and coaching sessions because the staff's shortage was probably perceived more. On the other hand, low urban hospitals offered more shopping services and additional break rooms.

For the second research question, there was suggestive evidence that resiliency involves multiple aspects of the healthcare system. One of the main lessons from the COVID-19 outbreak is that staff is a core asset for hospitals. It is recommended that organizations take care of the medical staff by offering services that support their well-being since it is connected to the quality of care delivered. The healthcare system is heavily dependent on patient-related employees and, therefore, the resiliency of the overall organization.

Still, it was also found that there are some valid recommendations for future hospital developments. Although, the COVID-19 pandemic did not change the core of the project brief or the general program of requirements. The experience of the crisis added force and impetus to the existing conditions. Six primary recommendations shown in figure 49 and explained in table 7 to increase flexibility, robustness and adaptability of future hospital design arose after the investigation.

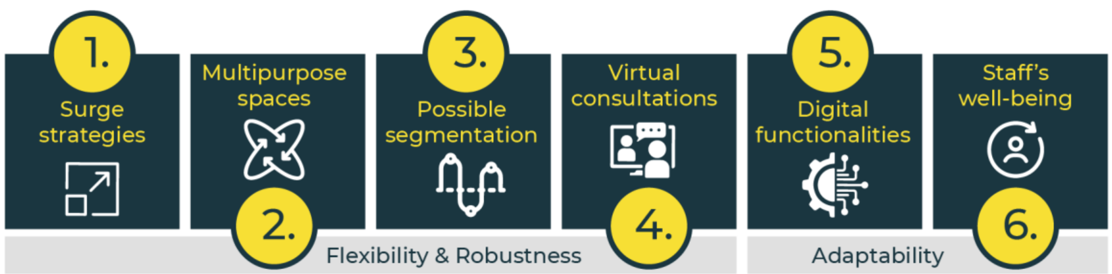

Figure 49. Recommendations for future hospital design based on the pandemic experience.

The first recommendation is to consider surge strategies in the nursing wards. There is suggestive evidence that future infectious diseases could be related to respiratory problems. Hence the number of "ventilation beds" in the nursing wards with mechanisms like Opti-flow could help respond to a surge respiratory crisis like occurred during the second and third waves of the pandemic, reducing the need for ICUs for treating patients with virus-like COVID-19.

Also, future design can consider multifunctional rooms to increase flexibility and scale-up quickly. Single-patient rooms could be designed technically and spatially for double occupancy in surge demand periods. Moreover, to improve the robustness of the design, future hospital developments could be more aware of the building's overall oxygen and power capacity, especially in the areas designated for infected patients, to avoid failures during the hospital lifetime. It was found during the research that some hospitals presented difficulties due to a lack of capacity in power and oxygen supply in the nursing wards.

The second recommendation is to consider the availability of multipurpose spaces like outdoor parking areas or atria inside the facilities. Multipurpose areas can help increase flexibility by installing pop-up services and temporary structures with additional equipment or supplies in the case is necessary for a future crisis.

Third, there should be a possibility of segmentation of wards for isolating infected patients within the building. Thus, “red” and “green areas should be conceived in the design stage, which involves independent traffic flows and independent installations. Separating the ventilation system in the units to compartmentalize the airflow of infected patients quickly might increase flexibility and robustness. Furthermore, it might avoid improvisation or structural changes in the building’s lifetime.

The fourth recommendation is related to the trend that digital consultations will continue in the long term. Therefore, spaces for virtual communication could be considered in the outpatient department. A proportion of consultation rooms might change to virtual mode, which might require adequate internet connectivity to support the telehealth experience and guarantee effective communication between patient and physician. Furthermore, the number of in-person consultations rooms could be rethought. Virtual consultation could help increase the system's capacity considering the growing group of patients that would require primary care in the future. It should also be considered that not all services could be effectively moved to a virtual platform. Understanding which functions could be delivered virtually and establishing clear guidance is essential to evaluate whether telehealth, in-person visit, or a hybrid method are more appropriate.

The fifth recommendation is related to the digital transformation of healthcare facilities. During the research, it was found that non-patient related staff will continue working from home regularly. Thus, a future design might consider a proportion of workplaces as a possible multipurpose space for storage or installation of additional equipment if necessary. Furthermore, to increase the adaptability of the facilities, services for staff like meeting rooms and break rooms should be suited with digital functionalities to support workers working from home.

The last recommendation seeks to increase the adaptability of hospitals. As mentioned before, the well-being of healthcare workers is connected to the care delivered. Thus, organizations could facilitate additional services for employees, especially in demanding periods, to take care of the medical staff and build towards more resilient healthcare systems.

Table 7. Summary recommendations for future hospital design based on the pandemic experience.

1. Surge strategies	2. Multipurpose spaces	3. Possible segmentation
Increasing the number of “ventilation beds” in the NW with mechanisms like Opti-flow could help respond to a surge respiratory crisis reducing the need for ICUs. Consider multifunctional rooms to scale-up quickly. Single-patient rooms could be designed for double occupancy in case of surge demand. The infrastructure for oxygen and power supply should also be geared to high demand.	Availability of open-air parking areas or spaces like atria inside to install pop-up services, triage, additional storage, equipment, or temporary structures connected to the building.	Possibility to differentiate infected from non-infected areas considering segregation of traffic flows, space functionality and installations (NW and ICUs). Separating the ventilation system in the units to compartmentalize the airflow from infected and non-infected patients easily, avoiding improvisation or structural changes during the building's lifetime.
4. Virtual consultations	**5. Digital functionalities**	**6. Staff's well-being**
Digital consultations might increase in the future. Not all services could be effectively moved to a virtual platform. Understanding which functions could be delivered is essential. Spaces for virtual communication should be arranged (internet connectivity with high-speed capabilities are necessary to support the telehealth experience).	Non-related patient staff will work more often from home. The use of working spaces might reduce in the future. Nevertheless, it can be used for other purposes like storage in a surge event. Include digital functionalities in breakrooms and meeting rooms.	Organizations could take care of the medical staff by offering additional services that support their well-being.(specially in demanding periods) E.g. Free parking services, childcare, restaurant. The healthcare system is heavily dependent on patient-related employees and, therefore, the resiliency of the overall organization.

5.1 Discussion

General difficulties in the pandemic response

One of the main difficulties in the pandemic response was the shortage of staff in the country. As a result, health workers from regular care had to collaborate in the emergency response, which caused discontinuity and reduced regular care during the crisis. Furthermore, some recently built hospitals presented technical difficulties during the outbreak while treating infected patients in the nursing wards due to a lack of capacity in the power and oxygen supply.

Future crises related to respiratory issues could be treated in the nursing wards with less invasive ventilation mechanisms like Opti flow rather than in ICUs with intubation, as occurred in the COVID-19 pandemic. Since the design stage, future hospital developments should be aware of the overall capacity of the power and oxygen supply in the assigned parts for infected patients to avoid failures during the building lifecycle.

In the coming years, there should be a combination of additional staff and infrastructure. Therefore, government policies could be oriented to decrease the shortage of healthcare workers. Moreover, the design of oxygen and power supply for future developments should respond to the high demand of patients with respiratory infectious diseases. Thus, the budget for oxygen supply could be reconsidered to increase the number of beds that could provide oxygen simultaneously.

Ventilation systems – HEPA filters
Changes in the ventilation systems of hospitals were done during the pandemic response. In areas with recirculation systems like wards where the ventilation system is designed independent for each room for patient's comfort, the installation of additional HEPA filters per unit was a solution to clean the contaminated air. Nevertheless, the installation of HEPA filters was the least enforced measure of the technical modifications. Although HEPA filters are not very expensive to install, the elevated maintenance costs and high energy consumption in the long term make them not an attractive solution. Many hospitals instead prefered to cohort covid care in departments during the crisis and declared all the area as infected.

Regarding future developments adding ventilation mechanisms to the building could be a convenient and efficient way to controlling the spread of infectious diseases. However, ventilation is very costly, and energy consumption, adding more might not be the way to achieve carbon-neutral hospitals in the future. In a future pandemic, the installation of HEPA filters is possible if it is considered necessary to control the spread of infectious disease, but not necessarily a permanent solution.

The unclarity of terminology
While developing the research, it was discovered that different interviewees had understood the term "cohort nursing" differently. In the investigation, cohort nursing was recognized as declaring a whole area as contaminated with infected patients. While in the interviews, the term also was seen as making dedicated wards of the hospitals just for COVID-19 care. Cohort accounted for the grouping covid-care regardless of how the patients were nursed or the rooms' layout. The unclarity of terminology could bias the research. Trying to find relations between the working practice of cohort nursing during the pandemic and the measures taken during the different waves might not be accurate since the term is understood in different ways, and the information collected might be misinterpreted.

5.2 Recommendations for future research
This research could be continued by collecting more data on the pandemic response. The survey could be distributed again to the hospitals that have not answered the questionnaire. The data could be analyzed using statistical techniques to find which variables are more significant and differentiate the measures taken during the pandemic. Additional research about future hospital design is essential to build resilient facilities; learning more from the COVID-19 experience can contribute to evidence-based design principles and improve healthcare facilities. Investigating future possible pandemics scenarios could also contribute to being more prepared for other future infections more contagious than COVID-19. Furthermore, research in the three additional aspects of healthcare resiliency: Staff, system, and supply chain is also desirable. For instance, within the staff aspect, investigating future employee well-being strategies could contribute to healthcare resilience. Another field of investigation could be digital innovation of healthcare, how technologies can support the care process and how this also affects space requirements and hospital settings. Finally, the main research findings for improving hospital design could be incorporated into the program of requirements and communicated to advisors, consultants, and other stakeholders involved with healthcare projects. Sharing knowledge and learning from past experiences could help to work collectively towards more resilient hospital design.

“Do it quickly, do it together”

6.1 Process

My interest in the healthcare topic developed mainly during the summer of 2020. I started thinking about my graduation research while the COVID-19 pandemic was already spreading globally and was becoming one of the most challenging situations of the last years in history. Most of the news was related to the virus's high infection rates and the apparent insufficient capacity of the healthcare systems in most countries. The crisis required the construction of entire new hospitals and transforming convention centers and other non-healthcare buildings into healthcare facilities. At that moment, I realized that healthcare projects and the current pandemic situation were potential and attractive research topics for my graduation.

I was looking for a relevant topic with a future-oriented perspective that complemented my professional experience designing and planning projects. Complementing what I enjoyed the most during the first year of my master studies, analyzing existing complex projects from a managerial perspective, creating strategies to have a more robust and resilient built environment. Therefore, I decided to dive into the consequences of the current pandemic to future-proof hospital projects as the primary research topic. The crisis occurred while I was trying to structure the investigation; it was challenging to have a clear, fixed overview of the research structure. The topic was very broad, and I needed to find a focus.

The thesis resulted in a practice-based study that was going to be shaped along the process. Thus, since the beginning, the investigation structure was dynamic as the pandemic was a new phenomenon, and not many previous scientific studies were made into the field.

6.2 Research approach

During the first phase of the research, P1 and P2, the investigation was more oriented towards hospital projects in the design phase. The purpose was to investigate what changes were being implemented in future projects based on the pandemic experience in the Netherlands. The methodology proposed was in-depth interviews with different design team members. If possible, combine them with medical professionals to deepen how medical staff evaluates the suitability of the design to support a future pandemic response. Hence, the engineering graduation company provided two case studies for the research, one in the Netherlands and Belgium; both projects were University hospitals in the preliminary design stage. Evaluating design teams and projects in the design phase was the approach proposed considering that the medical staff would be busy responding to the crisis and would not be able to help with the investigation.

Nevertheless, after researching the pandemic response and analyzing the measures taken in hospitals in the country, it was determined that a validation of the current situation was needed before considering any changes in the engineering company's design.

Furthermore, the development of multiple interviews using two case studies was very specific to each project, and a more general overview was desired. So, after P2, it was decided together with the engineering company and my mentors to change the methodology towards a broader perspective. A questionnaire was proposed to have a national-based overview of the changes and measures taken in hospitals in the Netherlands. It was decided first to investigate the pandemic's experience from a facility and real estate management perspective, rather than design team members, and afterwards make interviews to follow-up the survey outcomes. As a result, the aim and the objectives of the investigation were more related to examine how Dutch hospitals dealt with the different waves of the pandemic and investigate what lessons can be transferred to future hospital projects.

Collecting and processing the data

The development of the questionnaire was one of the most challenging parts of the research. After changing direction later P2, the survey structure needed to be aligned with the new objectives, which required more time than estimated. Furthermore, as the thesis is an exploratory practice-based study about the consequences of the COVID-19 pandemic, which is a new phenomenon, it was difficult to define the outcomes of the questionnaire using closed-answer questions. Furthermore, it was challenging to make the survey short, attractive, and focused on the main study principles and not on the details. Multiple versions of the survey were made to clarify the desired outcome measures and the most critical variables that were going to be analyzed.

For processing the data, the objective was to make a statistical analysis to consider the working practices during the pandemic, such as cohort nursing for COVID care, collaboration with other care to free up beds for covid patients, and locations 100% dedicated to non-covid care. However, after a preliminary analysis of the data collected from the survey, the previous outcome measures were not making a clear distinction between hospitals. Moreover, the responses from the survey were not enough to apply statistical techniques to identify if the relations find were significant or not. Therefore, it was decided only to use spatial characteristics of hospitals to identify patterns graphically through timelines and histograms.

Based on the patterns found to answer the first research question, the recommendations for future hospital design were made together with the qualitative analysis from the interviews.

6.3 Research topic

The investigation is conducted as part of the Management in the Built Environment department within the chair of Design and Construction Management (DCM). The core chair is based on design and construction processes involving understanding the project initiation phase, the architectural design, and tendering stage. Furthermore, the topic includes analysis and comprehension of the context where projects are being developed to steer them through the complex webs of requirements and relations to create added value during the life cycle of buildings.

The research topic addresses the spatial consequences of COVID-19 in future healthcare buildings. Hospitals are complex projects from a technical and organizational perspective delivered in an environment of uncertainties, driven by rapid technological advances and sudden changes in demands. During the pandemic, healthcare facilities had to change their operations and logistics to control the spread of the virus. In some cases, facilities were transformed to meet the new requirements for placing COVID-19 care. Thus, this topic is related to DCM in terms of studying the context and evaluating the existing hospital's design in terms of architectural quality and "fit for purpose" during the outbreak. The goal is to identify emerging design considerations for future hospital design. The output of the research is to provide recommendations and guidelines for future projects based on the lessons learned regarding the pandemic resiliency of the built environment.

The insights gained in this graduation project can contribute to the development of healthcare projects that adapt to future demands. Hospitals must be ready to support an increase in patients' number while delivering essential and regular care. It was found that convertibility and versatility in nursing wards are crucial for future design. "ventilation beds" could help overcome a future infectious disease without increasing ICUs in the hospital. Nevertheless, attention should be given to the oxygen and power capacity of the building to avoid technical failures throughout the building lifetime. Furthermore, multipurpose spaces inside and outside the hospital could support installing pop-up structures and excess storage needed in a crisis. Healthcare facilities must isolate and contain infectious patient care in different parts of the hospital to minimize transmission risk and provide a safe environment for staff and patients.

Moreover, it was found that digital consultation rooms should be considered in future design since virtual communication for examinations will continue developing in the coming years. Additionally, the adaptability of services for non-essential staff should be regarded since home-office is a trend that might affect the space required for workplaces. Lastly, digital functionalities in breakrooms and meeting rooms for medical staff should be provided to support the virtual communication increase. Thus, design should contribute to the well-being of healthcare workers during surge situations.

6.4 Dissemination

Social & scientific relevance

This graduation work has a societal relevance since it is likely that other outbreaks like COVID -19 occur in the future. The healthcare systems require facilities to accommodate emergent and unexpected needs, so regular care is not endangered, and the spatial environment is more prepared in times of a crisis. This research provides an overview of the pandemic preparedness in the Netherlands and provides recommendations about how hospital buildings can be more resistant to a future virus-like COVID-19.

The investigation can add value to future hospital design by helping hospital executives, facility directors, design teams, and healthcare consultants design or renovate spaces to address viruses like COVID-19.

Transferability

The conclusions and outputs of this research are recommendations that can be applied to future hospital projects. The goal is to help design more flexible, robust, adaptable, and resilient facilities to maintain regular operations during a possible future virus-like COVID-19.

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Appendix A

Survey Uw ziekenhuis tijdens COVID-19

Start of Block: Section 1 Introduction and respondent characteristics

Dear Madam, Sir,

What makes this project special is that we would like to learn how we can futureproof the design of hospital buildings to pandemics like COVID-19.

Would you like to participate in this survey and start the online questionnaire?

If you indicate below that you wish to participate in the study, you consent to the collection, storage, and inspection of the data you provide.

- ○ Yes, I would like to participate in the study (1)
- ○ No, I would rather not participate in the study (2)

Skip To: Q1 If QID261 = 1

Skip To: End of Survey If QID261 = 2

Page Break

Q1 What is your position in the healthcare organization?

- ○ Facility manager (1)
- ○ Real estate manager (2)
- ○ Facility/Real Estate advisor (4)
- ○ Facility/Real Estate director (5)
- ○ Logistics manager (6)
- ○ Other, namely (3) ____

Q2 Please fill out for how long have you worked in your current position?

- ○ Years (1) ____

Q3 What is the highest degree or level of education that you have completed?

- ○ MBO (1)
- ○ HBO (2)
- ○ WO-doctoraal or master (6)
- ○ Other, namely (11) ____

Page Break

End of Block: Section 1 Introduction and respondent characteristics

Start of Block: Section 2 COVID-19 Response in hospitals

This questionnaire is focused on the preparedness of the hospital building during the COVID-19 pandemic. The first section is about general characteristics of the facilities, then the survey will center on the operations and adaptations made to the buildings to respond to the outbreak. Finally, the last questions are about the future of the hospital after the pandemic experience. It is very valuable that you answer the whole questionnaire although you may not have all the specific information. If there is someone else in your organization who can answer further questions about COVID-19 measures taken in your hospital, please fill out your colleague's contact details at the end of the questionnaire.

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*

Q4 Please fill out the zip code of the hospital you work for.

If the hospital has more than one location, fill out the zipcode of the hospital's main location you are responsible for.

____

Page Break

Q4.A If your hospital had more than 1 location, did you have a location that was 100% dedicated to non-COVID care?

- ○ Yes (1)
- ○ No (2)
- ○ Other, namely (4) ____

Page Break

Display This Question:

If Q4.A = 1

Note: If your hospital has assigned locations only for COVID-19 patients.

Please answer the questions of the survey regarding the hospital's (main) location assigned to COVID-19 care.

Page Break

*

Q5 Please state the total number of beds in the hospital prior to the pandemic:

____

*

Q6 Please state the number of intensive care places prior to the pandemic:

____

*

Q7 Please indicate the percentage of single patient rooms in the inpatient wards prior to the pandemic:

____

Page Break

Q8 Did your hospital use cohort nursing for COVID-19 patients?

○ Yes (1)

○ No (2)

Q9 Did your hospital collaborate with local hotels and/or other care organizations to free up hospital beds for COVID-19 patients?

○ Yes, during the first wave (Feb 2020 - July 2020) (1)

○ Yes, during the second wave (Aug 2020 - Feb 2021) (2)

○ Yes, in both waves (3)

○ No (4)

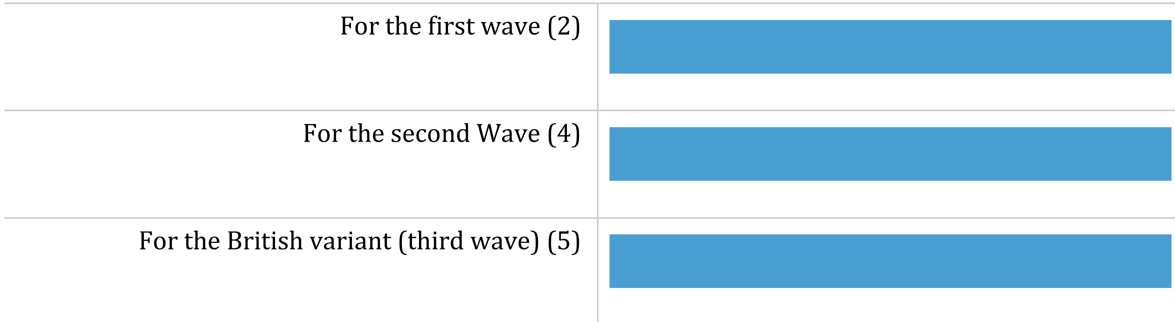
○ I Don't know (5)

Page Break

Q10 How well prepared do you consider your hospital was for the different stages of the COVID-19 pandemic ?

Mark a number on the scale between 0 to 10. Considering 0 as not at all prepared and 10 as very well prepared.

0	1	2	3	4	5	6	7	8	9	10


For the first wave (2)
For the second Wave (4)
For the British variant (third wave) (5)

Page Break

Q11 Could you indicate if and in which month the following **physical interventions** were introduced in your hospital?
Please choose the year and fill out the number of the month in which the measure was implemented.
If the measure was not introduced, please fill out the number 0.

Measure	Year			Month
	2020 (1)	2021 (2)	I don't know (3)	0, 1 to 12 (1)
Put up visual cues (e.g. limiting amount of people in elevators, routes marked on floor) (6)				
Provision of hand-alcohol at entrances (7)				
Install cough-barriers between patients and staff at desks (16)				
Enhance visual communication between staff (glass in doors, plastic barriers) (8)				
Repurpose spaces into ICU-capacity (14)				
Separation of entrances for infected and non-infected patients (13)				
Segmentation of wards with infected and non-infected patients (17)				
Segregation of 'red' (potentially infected) and 'green' (triaged, non-infected) flows (patients, visitors and staff) throughout the hospital (18)				
Dedicated entrances for staff (19)				
Otherwise, namely (20)				

Q12 Could you indicate if and in which month the following **technical interventions** were introduced in your hospital?
Please choose the year and fill out the number of the month in which the measure was implemented.
If the measure was not introduced, please fill out the number 0.

Measure	Year			Month
	2020 (1)	2021 (2)	I don't know (3)	0, 1 to 12 (1)
(Partial) switch to digital consultations (1)				
Advanced monitoring (equipment) in COVID-wards (4)				
Additional monitoring for surge ICU-capacity (2)				
Install air-pressure barriers between 'red' and 'green' zones (3)				
Install extra communication systems (for patient in isolation) (6)				
Install extra communication systems (between staff) (7)				
Changes to the general ventilation systems (8)				
Local filtration fixtures (HEPA) (9)				
Otherwise, namely (10)				

Q13 Could you indicate if and in which month the following **services for staff** were introduced in your hospital?
Please choose the year and fill out the number of the month in which the measure was

implemented.
If the measure was not introduced, please fill out the number 0.

Measure	Year			Month
	2020 (1)	2021 (2)	I don't know (3)	0, 1 to 12 (1)
Additional break rooms (to physical distance) (1)				
Additional attention for mental well-being (2)				
Information sessions for staff (live-stream, intranet, e-mail) (3)				
General support: child care (5)				
General support: additional/free parking (6)				
General support: shopping services (or drop off) (7)				
Temporary accommodation in local hotels (8)				
Non-essential staff working from home (9)				
Otherwise, namely (10)				

Q14 Are you planning to have a refurbishment or renovation of (part) of your hospital building?

○ Yes (5)

○ No (6)

Page Break

Display This Question:

If Q14 = 6

Q14.A Are you already including COVID-19 measures in your facilities to futureproof hospital building to?

- ○ Yes (1)
- ○ No (2)

Page Break

Q15 Assuming there will be a renovation in the coming years, which interventions related to COVID-19 would you recommend to be included in the design?

____

____

____

____

____

End of Block: Section 2 COVID-19 Response in hospitals

Start of Block: Ending

Q16 Do you have a floor plan of the hospital that you could share with us for this research project? Could you please email the file to m.a.preteltduque@student.tudelft.nl

It would be useful if the floorplan contains the departments most involved in delivering the COVID-care, such as: emergency department, ICU, and nursing wards.

- ◯ Yes, I will email the floor plan (4)
- ◯ No (5)

Q17 Would you like to participate in the prize draw?

(If you win a prize, we will contact you)

- ◯ Yes (1)
- ◯ No, thank you (2)

Q18 Would you like to receive a summary of the results of this study?

- ◯ Yes (1)
- ◯ No, thank you (2)

Q19
We are planning to do additional interviews to better underestand the outcomes of the survey.

Are you willing to participate in a follow-up interview?

You do not have to decide now whether you really participate, you will only be asked if we can approach you with a request. You can always refuse.

◯ Yes, you can use my data to contact me again with a request to participate in an interview to complement the research. (4)

◯ No, I do not want to be asked again to participate in this research project. (3)

Display This Question:

If Q17 = 1

Or Q18 = 1

Or Q19 = 4

Q20 Would you please leave your contact details below (name, email)?

◯ Name (3) ____

◯ Email (1) ____

Q21 You may feel that we should (also) contact a colleague about this research or the follow-up interview. If so, could you please leave their contact details here as well?

◯ Name (1) ____

◯ Email (2) ____

Q22 Is there anything you would like to advise, mention or comment?

____

End of Block: Ending

Appendix B
Interview protocol

Small talk and developing rapport 0-5 min (5 minutes)

0. Introduction
Thanks for meeting with me...
nice to meet you...

Context questions and current situation 5 – 45 min (40 minutes)

Last year, when the pandemic started in the Netherlands, there were already images from the situation in China, Spain and Italy and the number of cases overwhelming health care systems, and the challenging situation that hospitals were going to face…

1. Can you tell me something about the crisis organization and crisis preparedness in your hospital?
- *What kind of contingency plans and protocols were available?*
- *Had a pandemic been contemplated in any way?*
- *Had pandemic scenarios been practiced before COVID-19?*

2. Were you yourself involved in the crisis / outbreak management team?
- *What was your relationship with the crisis management team?*
- *Did you contribute to the development of strategies for the emergency response?*
- *How was real estate represented in your crisis organization?*

3. Can you tell me about the decision-making process regarding the modifications made to the building, equipment and the services that were needed?
- *How was it decided what measures were necessary?*
- *Did the hospital use advice from consultants or other external expertise to organize the response to make informed decisions (e.g., space modifications, expand capacity, hospitals services)?*
- *How would you describe the attitude towards speed and costs of modifications that were consider necessary?*
- *Did you experienced any pitfalls in the measures taken?*

4. What strategies/policies were developed or adopted to provide care and manage the growing numbers of COVID-19 patients?
- *Can you tell me about the testing policy for staff?*
- *Do you know if the medical staff treating infected patients had high rates of infection?*
- *And what about the testing policy for patients and visitors?*
- *Did the hospital keep visiting hours for patients in isolation in some form? How, or if not, what was done to keep family member connected/informed?*
-*Where there any changes in the policies during the different phases of the outbreak? (give examples)*

5. What were the expectations regarding the duration of the pandemic?
-*The measures that were taken were initially considered only in the short term?*

- Has the perception of the crisis and the decisions taken changed over time? (can you give examples)

6. How did the hospital cope with regular care during the different phases?
- Did the strategies and measures taken affect regular care? (repurposed spaces, stop of operations)
-Do you think is possible to continue delivering elective and regular care while providing covid care?

From your response in the survey, I can see that your hospital segregated flows into infected and non-infected streams.

7. Was the segregation of "green" and "red" flows a new practice during the pandemic?
- Maybe you can show me in a floor plan the trajectory of each of the flows? (which areas or medical departments crossed the red stream?) (adjacency of departments?)
- What kind of measures were taken to either separate patient flows or make transportation safe during the transport of COVID-19 patients?
- Are you aware of the difficulties experienced when transporting infected patients within the hospital?

<u>Future overview questions 45-55 min (10 minutes)</u>

Now speaking more towards the long-term run…

8. What elements should be included in the design brief of future healthcare facilities?
- e.g. You mentioned that digitalization of care is desirable and more digital functionalities should be pursued, could you elaborate on this idea?

After dealing with the COVID-19 pandemic for more than a year...
Once things are more relax with the pandemic, what would you say is important for the future?

9. Should any measures be taken to make your hospital facilities fit for purpose?

10. What are the main lessons learned from the COVID-19 pandemic experience?

<u>Closing questions 55-60 min (5 minutes)</u>

11. Is there anything you would like to add before closing off the interview?

Thank you for your participation in our research project…

Appendix C

Planning schedule

Research process	Working period
Research background	September 2020 – January 2021
Questionnaire preparation	February 2021
Questionnaire distribution	Second half March 2021
P3- Reflection	April 8th
Data analysis + Interview protocol preparation	The second half of April 2021
Interview(s) + Data analysis + findings	First half of May 2021
P4 – Preliminary findings conclusion/ reflection	May 25th , 2021
Additional interviews + data analysis	June 2021
P5Conclusion/Discussion/reflection/recommendations	June 29th 2021