Redesigning Hospital Spaces on the Fly to Protect Healthcare Workers

The Challenge

The novel coronavirus (COVID-19) has posed an unprecedented challenge to healthcare infrastructure around the world. What Dr. Paul Farmer calls "staff, stuff, space, and systems" have been pushed to their limit. There have been many stories about the crisis of stuff, staff, and systems, but fewer discussions about space. One reality that links them together is that healthcare workers—who are particularly vulnerable to exposure and more severe infection— must remain healthy in order to protect patients, families, and communities. And the design of hospital spaces must help protect us.

The space of the hospital itself however, will continue to facilitate nosocomial (hospital borne) infection, unless infection control protocols are established and adhered to. And herein lies the problem: validated protocols designed to prevent COVID-19 transmission do not yet exist, and therefore hospitals are implementing spatial redesigns on the fly, doing their best to learn from protocols based on other diseases, like Ebola and tuberculosis.

Until we can better understand the virus' pathways, we won't be able to confidently redesign our existing spaces to adhere to new and higher standards of infection control guidelines. In the meantime, hospitals will continue to repurpose and convert their spaces adhoc to meet surge demand—adapting idealized infection control protocols to unideal spaces and situations. This means healthcare workers and administrators must quickly adapt inflexible spaces, recognizing that the resulting adaptations may put healthcare workers and our communities at risk unless we can quickly create site-specific guidelines that are adherable and implementable based on the best available knowledge. So while we need research to understand who is at increased risk for complications of COVID-19 and to develop effective vaccines and best therapies, we also need research that identifies how spatial design and awareness can mitigate risk.

Learning from a Frontline Hospital

The following case is an example of how clinicians at Mount Sinai Hospital in New York City, researchers, and designers came together to understand the constraints of adapting guidelines to imperfect spaces, and the lessons we believe other institutions can learn from this.


Shortly after the Shelter-in-Place order was issued by the Governor of New York in mid-March, Mount Sinai transformed its entire care delivery system and carried out significant infrastructure modifications to address the COVID-19 outbreak. With the support of hospital leadership, John Bucuvalas, MD (Vice-Chair of Faculty Affairs and Professor of Pediatrics, Icahn School of Medicine at Mount Sinai and Mount Sinai Kravis Children's Hospital) and Michael Dolinger, MD, MBA (Chief Pediatric Fellow within the Mount Sinai Kravis Children's Hospital), recognized an opportunity to gather learnings related to spatial design interventions in inpatient care units for COVID-19 patients that might be shared with other institutions. They reached out to MASS Design Group to bring its lessons from designing for global epidemics, who in turn linked the partnership to Ariadne Labs, the health systems innovation center founded by Atul Gawande.

This document presents a three-week spatial research methodology that took place within a frontline hospital at the epicenter of the COVID pandemic in New York City, with the goals of:

- bringing light to the challenge of adapting idealized design guides to site-specific conditions,
- capturing quick interventions that are working,
- offering a new hypothesis and framework to guide future design interventions, and
- sharing our lessons to assist other medical facilities as they pursue their own necessary spatial adaptations moving forward.

Takeaways
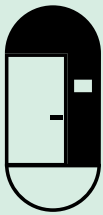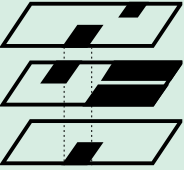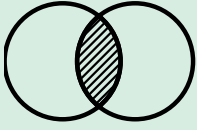
1. While infection control protocols are being quickly adopted, hospitals are not designed to easily pivot to support the infrastructural changes needed at the scale of a pandemic surge. One major shift is the focus from individual patient care to unit care, creating caregiving processes for COVID-19 units that place a heavy reliance on interstitial spaces. This lesson means that enforcing proper infection control protocols in hallways and key thresholds, like entries into units, may be as important as in patient rooms.

2. Variability exists both in the adaptations from floor to floor and unit by unit, as well as in personal perception of risk zones within care units. These differences affect how health workers behave and interact, sometimes introducing new elements that may impact the risk of infection among staff and patients.

3. Spatial literacy (i.e., the ability to read and understand space) can be a powerful tool to orient healthcare workers within unfamiliar and rapidly-changing COVID-19 caregiving environments. Simple visual aids and design nudges can help mitigate infection transmission by clearly conveying risk zones, creating mental "anchors" for specific activities, and aligning behavior with policy. Design can help advance the sociology of infection control, along with our developing understanding of its biology.

Next Steps

More collaboration and research is needed between healthcare workers, facility decision makers, and designers to help develop greater spatial literacy and to implement and iterate strategic design interventions. Thoughtful and simple spatial adaptations can help create situational awareness for COVID-19 units, set clear and consistent protocols for thresholds, align appropriate behavior within well-demarcated risk zones, and identify opportunities to more safely and flexibly expand capacity during surge conditions.

Our intent is to assemble a learning collaborative of health systems to rapidly share insights and best practices. Together, the collaborative will develop clear spatial guidance that can be used globally to transform hospital units, with the ultimate goal of protecting healthcare workers and allowing for safer treatment of critically ill patients and their family members in this new COVID-19 era.

Please note: This document is not intended to serve as design guidelines. It is a representation of lessons learned from a quickly implemented design research methodology. Additional research, more case studies, testing, and iteration are needed to create formal guidelines for infection control during pandemic surges like COVID-19.

Methodology

During the week of April 6, a team of clinicians and designers from Mount Sinai Kravis Children's Hospital and Mount Sinai Hospital, MASS Design Group, and Ariadne Labs investigated spaces converted and repurposed for the care of critically ill COVID-19 patients. Drawing from MASS's infection control design experience and evidence-based research experience, Ariadne Lab's public health innovation pathway and knowledge sharing model, and Mount Sinai's position on the frontlines of the NYC epidemic, the team sought to illuminate COVID-19 capacity planning, interventions, and opportunities.

Virtual walkthroughs of active COVID-19 patient care units
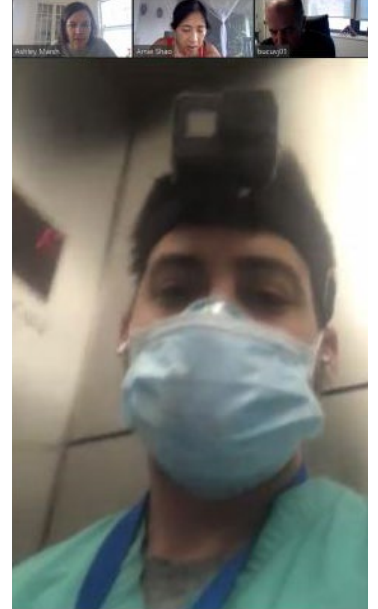
The rapid response spatial study focused on three units converted and repurposed for COVID-19, including an adult intensive care units (ICU) unit, an adult medical-surgical unit, and a pediatric unit. Using action cameras (GoPro) and cloud-based videoconferencing (Zoom), Mount Sinai clinicians helped designers remotely peer into active COVID-19 units, create "heatmap" annotations of perceived risk by frontline clinicians, and conduct interviews with Clinical Operations and Facilities leadership.

The team documented observations through on-the-fly sketches, drawing exercises, and photographs; and also generated graphics like the diagram to the far right to better depict conditions and recommendations.

Tinted film to alert people to risk zones

Tape, paint, or vinyl adhesive on floor
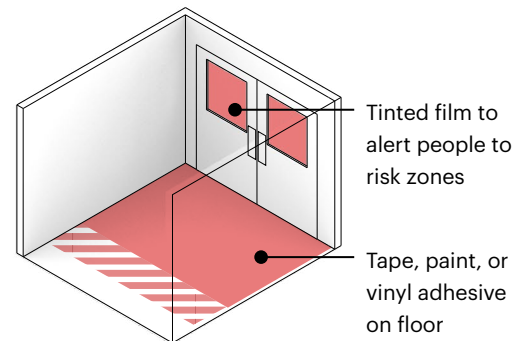
Together, the practitioners, designers, and researchers identified and documented interventions, discussed our understanding of limitations, and recommended next steps to furthering a shared understanding of design interventions and strategies.

Pre-COVID-19 Design Standards

Many design recommendations from before the current coronavirus pandemic exist regarding idealized conditions for treating patients and protecting healthcare workers.

For highly contagious infectious diseases, negative pressure isolation rooms are the standard of care. These are single patient rooms designed with antechambers and specialized airflow precautions. To prevent contaminated air from spreading into the rest of the hospital, rooms must be fully sealed, achieve a specific number of air changes per hour, ensure negative pressure (preventing room air from entering the hallway), and safely exhaust contaminated air. For diseases spread through direct contact, like Ebola, other infection control precautions are layered on—such as carefully choreographed routes for patient and staff movement across the facility and special surface sanitization measures.

Diagram representing the setup of a negative pressure isolation room
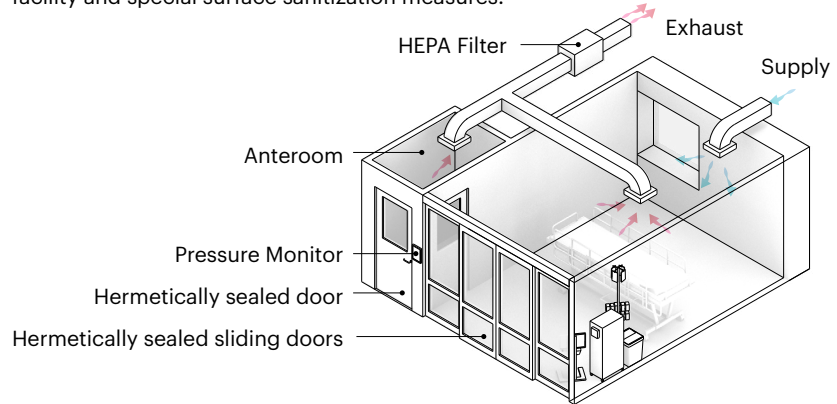
Until recently, however, hospitals have accommodated infectious disease patients as the exception, not the norm. Most large urban hospitals in America have a handful of negative pressure isolation rooms. Prior to COVID-19, and during the very early stages of the outbreak, this was enough. But what happens when a hospital needs to be able to accommodate hundreds of patients under pandemic conditions? This is what Mount Sinai faced in March.

Case Study
Mount Sinai Hospital

In less than three weeks, beginning in mid-March, the Mount Sinai Leadership redeployed healthcare workers to COVID-19 units, backfilled the gaps by shifting provider responsibilities, implemented a new shift system to minimize risk to health workers during shift change, established complex PPE distribution and recycling systems, implemented donning/doffing practices, postponed elective procedures to create capacity for the coronavirus surge, rapidly implemented telehealth services, restructured research efforts to focus on the pandemic, and committed resources to provide ongoing support for frontline workers including childcare, transportation, and psycho-social support.

During the same period of time, the Infection Prevention and Clinical Operations and Facilities teams at Mount Sinai Hospital worked to significantly expand the hospital's COVID-19 bed capacity in anticipation of a surge. The novel coronavirus forced healthcare facilities to broaden their focus from the individual patient room to the entire care unit. Mount Sinai built a 100-bed step-down care unit in the hospital's atrium (below left), and in partnership with Samaritan's Purse erected a temporary 68-bed tent facility (below right).

*Photos showing the main typologies of space they converted/repurposed*
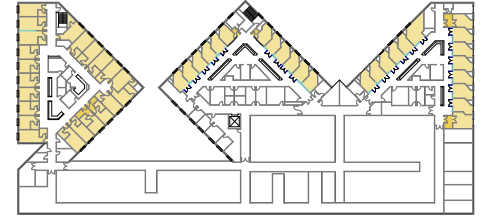
Spatial modifications during the surge

The hospital additionally converted 260 existing patient rooms into negative pressure isolation rooms. Within adult ICUs designated for COVID-19 care, tremendous changes took place. Walls and doors were constructed across the front of previously open ICU bays, and measures were taken to ensure fully sealed patient spaces. Large high-efficiency particulate air (HEPA) filter units were brought into rooms and set up to directly exhaust out windows that were fitted with wood panels. Intravenous fluids and patient monitors were pulled out into hallways to minimize provider exposure and allow for safer and easier monitoring (see photo on the left). PPE waste and recycling bins were dedicated to each unit, and protocols were established to bring these materials to dedicated service elevators in an effort to minimize cross-contamination.

IV fluids and monitors in the hallways
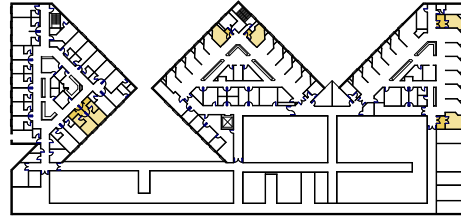
Before: 6 isolation rooms

Negative pressure isolation rooms on 6th floor of Guggenheim Pavilion

After: 48 isolation rooms

◼ Negative pressure isolation rooms

Diagram of interventions on the Guggenheim Pavilion
The diagram below highlights different interventions that were made to turn this adult ICU wing into one that could treat patients who have tested positive for coronavirus.

Original Negative Pressure Rooms
Previously, each side of the ICU wing only had one negative pressure room.

Vitals & Waste Management
Vitals, IV drips, medical equipment, and waste bins were moved outside of each room to minimize contact between staff and patients.

HEPA filters
HEPA filter units were installed in rooms and exhausted out windows that were fitted with plywood panels to provide a tight seal.

Don/Doff Zone
Space for donning and doffing PPE was located at the entrance of units

Visibility
Views into each ICU room from the nursing station were maintained by sealing the wall in plastic sheeting wrapped around metal studs.

Makeshift Negative Pressure Rooms
By enclosing each ICU bay and inserting a HEPA filter in each space, Mount Sinai expanded the number of negative pressure rooms for the most severe COVID-19 cases.
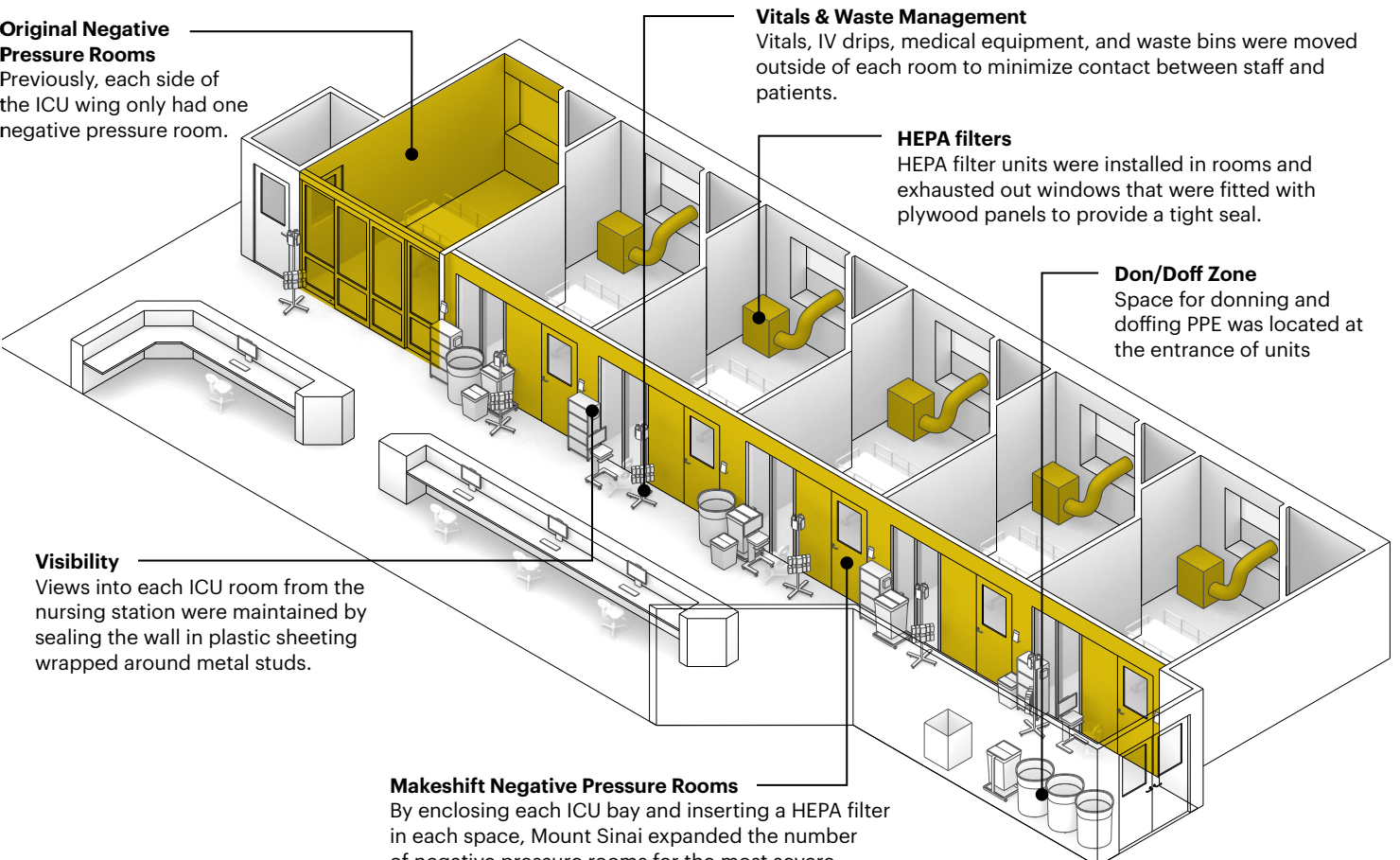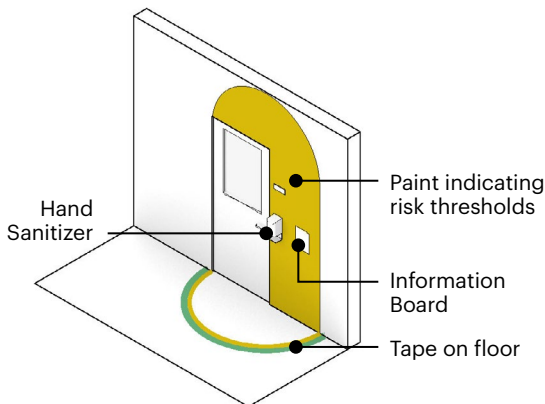
Design hacks

Mount Sinai's administrative, Clinical Operations, and Infection Prevention teams worked together to create physical changes to reinforce the programmatic and behavioral protocols implemented on COVID-19 floors. Specifically, they sought to include visual cues at key moments of risk or transition: for example, doors into patient rooms, PPE storage and access locations, and thresholds between different areas of risk. In some places, they installed signage indicating "extended use PPE zones," designated boxes for recycling face masks, and installed additional hand sanitizers to signal to staff upon entering or exiting key thresholds. These physical or cognitive "anchors" helped to designate functional use of space and reinforce patterns of work within these constraints. Other anchoring mechanisms could include tape on the floor, signage, and intentionally placed whiteboards or paint.

Stations to access PPE were provided at key locations, which in turn affected how and where healthcare providers utilized the equipment. PPE carts and instructional signage were located on every COVID-19 unit, a brown bag system was created to designate and store face masks for individual providers, and a peer approval system was implemented—requiring nurses to fill out a donning/doffing record sheet with "buddies" signing off on proper PPE application. Additional interventions that may increase PPE adherence in the future include: demarcating designated "clean" zones around PPE carts and donning areas, creating more predictable placements for essential equipment and resources, making access to PPE less high-touch, and developing a more consistent system for brown bag storage (either consolidated near the unit entrance, or affiliated with specific patient rooms).
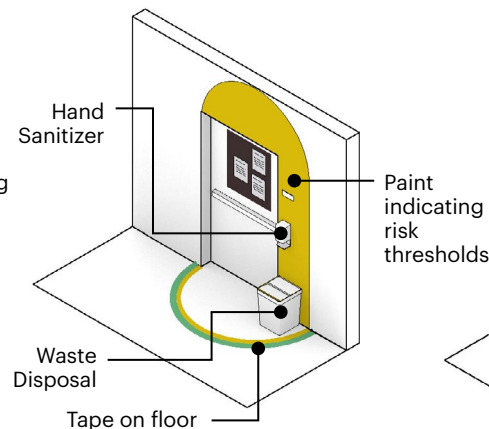
Entry into patient rooms

Hand Sanitizer

Paint indicating risk thresholds

Information Board

Tape on floor

Exit from patient care unit

Hand Sanitizer

Paint indicating risk thresholds

Waste Disposal

Tape on floor

PPE access & storage

Paint indicating risk thresholds

PPE

Hooks for hanging PPE brown bags

Instructional signage

Low-touch drawers

Tape on floor

Objectives

- Create awareness around what risk zones staff are entering vs exiting
- Convey key information at a glance (such as whether patients are intubated)
- Increase staff efficiency

Objectives

- Create awareness around what risk zone staff are exiting vs entering
- Remind staff to get clean before leaving contaminated zones
- Reduce unnecessary movement between units
- Reduce disease transmission to non-COVID units
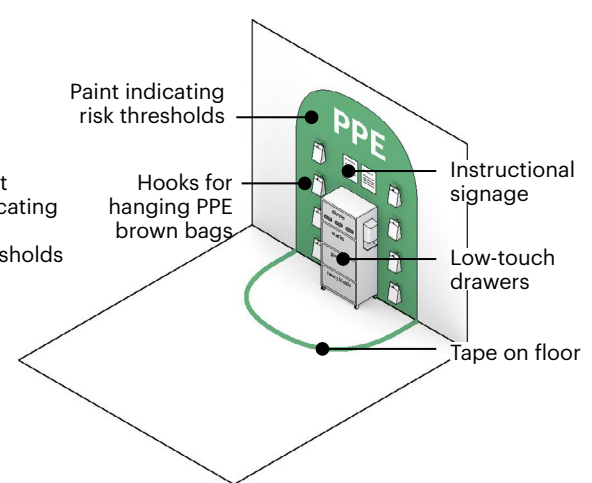
Objectives

- Create clear clean zones around PPE carts and donning areas
- Consolidate needed resources in one place
- Increase PPE adherence
- Reduce time and hassle in donning PPE
- Reduce PPE cart contamination

Compliance gaps and implementation challenges

Even with Mount Sinai's ingenuity and innovation in achieving a radical transformation in a short timeframe, adapting the existing hospital proved to be a difficult task. Changes were ultimately bounded by inherited and inflexible infrastructure. Within adult ICU units, it was not possible to integrate antechambers due to the spatial constraints of the floorplan, as well as the need to maintain direct visibility and access to patient rooms for high-level nursing care. Shifting IVs and monitors outside the patient room was necessary, but created more congestion in the corridors. And while the HEPA filtration fixtures were necessary, they took up an immense amount of space within patient rooms and were loud, constraining staff movement, communication, and workflows.


In older, smaller buildings like those that housed the pediatric units, repurposing spaces for coronavirus care was even more challenging. The presence of larger clinical care teams (reflecting higher nurse-to-patient ratios and more ancillary staff), alongside the need to minimize staff exposure within patient rooms, meant that more providers were working in hallways and compromising spatial distancing.

In buildings laid out without centralized nursing stations, this prompted the distribution of individual nurse computer stations along the hallway. Combined with the addition of PPE carts and recycling bins, as well as more complex cleaning and disposal protocols, the result was hallways crowded with equipment (pictured above). Particularly in critically ill patient spaces, this left little room for clinician rounding to comply with social distancing recommendations, and introduced inefficiencies that made nurses' work slower.

Beyond the size, layout, and flexibility of units, spatial perception emerged as another important factor. Clinician discussions and floor plan annotation exercises revealed inconsistent perceptions of risk zones within units, and the need for stronger spatial cues. Unlike typical care contexts, where providers work on units they are familiar with, and with teams they are familiar with, COVID-19 providers may be working for the first time in new spaces, collaborating with new team members, and may even be providing a type of care that is not their specialty (for example neonatologists caring for adult ICU patients). In medical decision-making, providers have been trained to weigh the level of risk against the potential for positive outcomes. But within COVID-19 units, the risk level of different spaces is not always clear or something clinicians consciously think about.

Developing Spatial Literacy

Terms like spatial literacy are underutilized in the research world but are especially prescient in a moment like this. As individuals, our spatial literacy around our bodies and our proximity to others has been unexpectedly heightened over recent weeks. The simple act of asking a clinician to annotate a heatmap by color-coding spaces to infection risk was revealing. The exercise generated interesting discussion and helped clinicians deeply consider space in a new way and rethink existing assumptions. The heatmap created for the pediatric COVID-19 unit also made visible an important design challenge: controlling movement across units. Particularly in tight, vertical healthcare settings, like the Mount Sinai Kravis Children's Hospital, healthcare teams needed to leave units in order to access key shared spaces like nurses lounges, or fetch resources like drugs or supplies. To limit nosocomial infection between COVID-19 and non-COVID-19 units, thresholds between floors (i.e., elevators and stairs) needed to be considered more closely, but proved difficult given the constraints in this building.
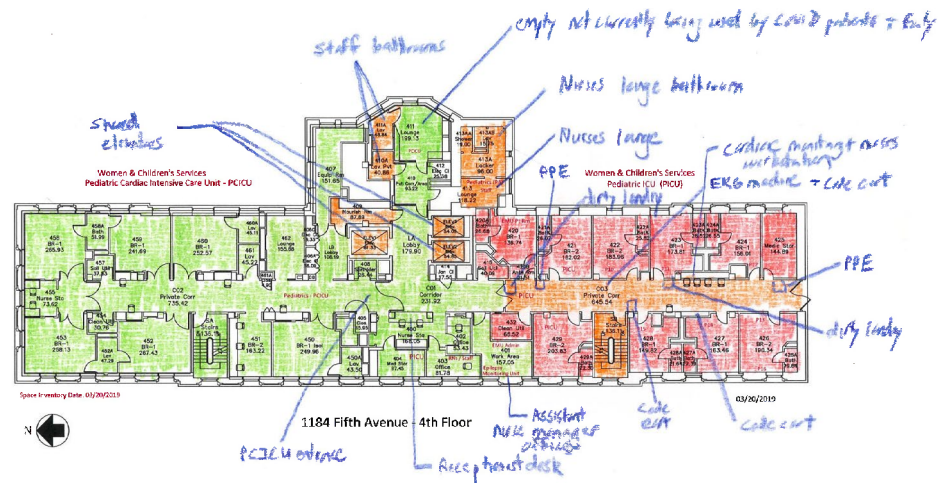
Annotated floorplan of pediatric COVID-19 unit by Mount Sinai clinicians

Annotated heatmaps of the adult ICU units revealed significant differences in individual perceptions of risk zones. This is notable because staff behavior is typically most stringent in areas perceived as red zones, where the risk of contagion is perceived as high; but there were varying degrees of adherence to infection control rules in spaces perceived as orange or green, and differing levels of legibility of which spaces carried high risks of contagion.

Because of this ambiguity, "warm zones" may be dangerous for healthcare workers simply because they are not aware that they are warm zones. In warm zones, healthcare workers might overlap with staff coming from or going to other floors, or on-call clinicians might be changing personal protective equipment (PPE).

At a bare minimum, health facilities can leverage design cues to clearly mark orange areas as "warm zones" and convey expected behavior to healthcare workers within these areas. At the same time, they can implement active interventions to try and lower infection transmission in these areas—that is, turning orange spaces into green ones.

We asked three different clinicians to annotate heatmaps of ICU units on the same floor. Their drawings revealed three very different perspectives on risk.

■ *"Hot" areas known to be contaminated, where providers should use full infection control precautions and be on alert*

■ *"Clean" areas that are fairly confidently non-infected areas, where staff can use relaxed precautions.*

■ *"Warm" or unclear areas that may actually pose risk even if not perceived as a risk zone.*

Together in conversation with staff at Mount Sinai, the research team identified red, orange, and green zones under pandemic surge conditions. In the condition of a massive increase in infection control rooms, the entire unit effectively becomes an orange zone, and clearly marked donning and doffing areas need to exist at major entrances to the unit, in addition to patient room thresholds. All possible measures should be taken to ensure that stairs and elevators in vertical hospitals stay uncontaminated, as they connect many different zones; and tape, signage, or paint can be used to designate these different risk areas and thresholds more clearly.

Risk zones of an adult ICU floor during pandemic surge conditions. Sketch shows the zones in the Med-Surg and ICU units on 6th floor of Guggenheim Pavilion

Donning/doffing zone for units
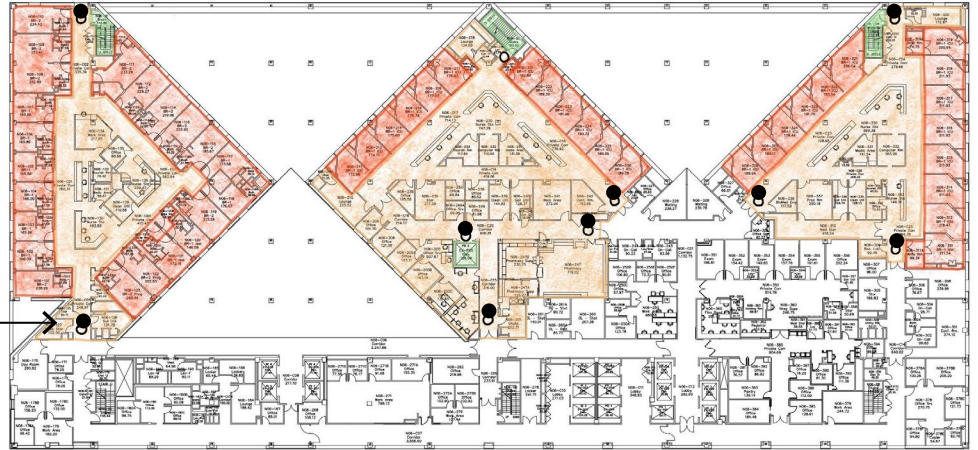
Conclusions

Our preliminary conclusions suggest that while revised infection control practices have been quickly adopted, medical facilities are not configured to adapt easily to these rigid adherence protocols. Instead, they are forced to respond "on the fly" in situ, often with insufficient amounts of equipment, protective gear, or clear guidelines. Amidst heroic efforts to transform hospital-wide clinical processes and infrastructure, adaptations can vary floor to floor and unit by unit, often revealing design "hacks" that are both creative and discordant. Nevertheless, hospitals are not designed for pandemic surge, and existing infection control protocols are inadequate for COVID 19.

More research and strategies in partnership with healthcare staff and designers are needed to help develop spatial literacy among providers and to use the built environment to facilitate this knowledge. Thoughtful spatial interventions can help create situational awareness for COVID-19 units, set clear and consistent protocols for thresholds, align appropriate behavior within well demarcated risk zones, and identify opportunities to more safely and flexibly expand capacity during surge conditions.

These interventions are needed now, but they will not be short-lived. And they will be even more necessary in hospitals with fewer resources. As we continue to realign care infrastructure and processes to the new normal, clinicians, designers, and administrators must work together to make invisible risks more visible, and create spaces that instill order, collaboration, and morale.