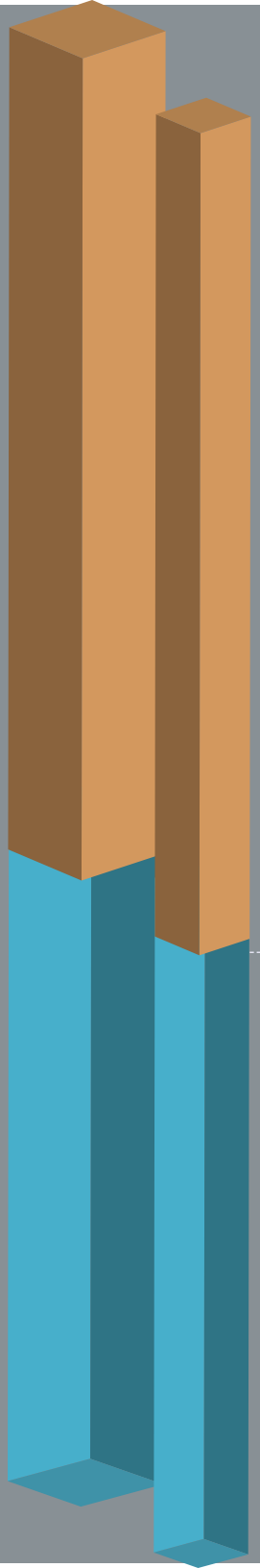


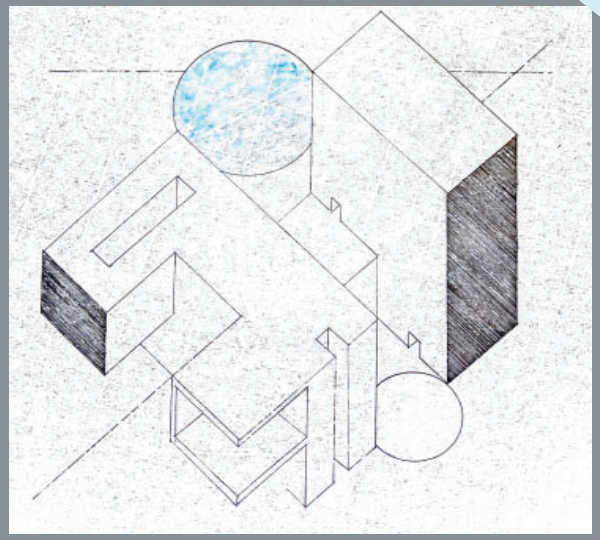
EFFICACY OF MODULAR DESIGN IN HEALTHCARE

RESEARCH REPORT • ADVANCED ARCHITECTURAL DESIGN STUDIO • NORTH DAKOTA STATE UNIVERSITY • DANIEL HECKMANN

Fall 2022
Under the guidance of dr. ganapathy mahal-

INTRODUCTION

Modular design has become an industry leading philosophy for the future of community-based health services. Modular applied as a design principle subdivides a construction system into independently fabricated units, similar in size, shape, and functionality to formulate a structure. The benefits of this approach include time-to-build efficiency, cost-effectiveness, quality and precision, sustainability, continuity, and modification. This process contradicts traditional construction, pre-fabricating spaces off site to be assembled later. Modular architecture is historically correlated with hotel design and is still in its adolescent stage being integrated into hospice. Forward-thinking medical institutes and design firms have begun to experiment with modular design in their projects aiming to provide accessible healthcare in any context, however, discrepancies have surfaced. The complexity of a functional healthcare facility including circulation, adaptability, materiality, and utilities are being overlooked due to monetary hesitation, high demand, and standardized design. Modular healthcare design is still unpopular amongst manufacturers and firms. Through correlational research and simulation software, modular solutions and traditional construction methods can be compared using operational statistics. The purpose of this research is to study the efficacy of the designs proposed by the industry thus far in hopes to refine the process for a safer, enjoyable, more efficient, and replicable solution.



BACKGROUND

In practice, study, and design; the application of medicine is steadily evolving to treat larger collectives of patients, demanding more ambulatory services and outmigration care. While not the first health crisis to spark this paradigm shift, **COVID-19** has proven that the field of medicine was **ill-prepared** for the pandemic; most notably in construction and design. The Rural Policy Research Institute (RUPRI) found that Rural Americans died at nearly twice the rate of their urban counterparts. Public health, both rural and urban was reliant on temporary pop-up clinics and testing sites enclosed in tents, pharmacies and venues mostly located in urban cities and state capitals. Those with more suitable infrastructure were constructed using shipping containers which lacked some of the basic facilities necessary for emergency medical care and testing. The issue of proximity, cost and efficiency deterred the possibility of many urban citizens and most rural citizens from receiving adequate professional medical help. Because of this, medical institutes were convinced that **modular construction** had potential. Cannon Design, headquartered in New York is one of the firms testing this theory. "Creating exam rooms offsite and then delivering them to the construction site can reduce the project schedule significantly (usually 15-20 percent), allowing doors to open sooner for the patient population" (CannonDesign). Their quantitative research presents an abundance of benefits, in fact, most research agrees. A study conducted by Dodge Data & Analytics claims that "healthcare facilities accounted for 24 percent of building types using permanent modular construction." The field is shifting rapidly since the pandemic and therefore it is imperative that time-to-build efficiency doesn't **overshadow quality**. Comparing modular solutions across different projects, the modules themselves share similar or exact layouts and functionality, arresting the possibility of creativity and efficient circulation. Furthermore, the standard cube-shaped modules don't offer the same freedom of **stick-built buildings**. Therefore, the enfilade of spaces are congested blockades of rooms methodically grouped in accordance with code. While modular healthcare facilities are a statistically sound solution backed by research, the designs lack the functionality and creativity of their traditionally constructed counterparts. By **simulating** the process of traditionally constructed healthcare facilities as a control variable, proposed modular solutions can be **compared and studied** to define what works well and what doesn't. Analysing what the industry has accomplished to restructure the design philosophy for a better medical facility, **one mod at a time.**

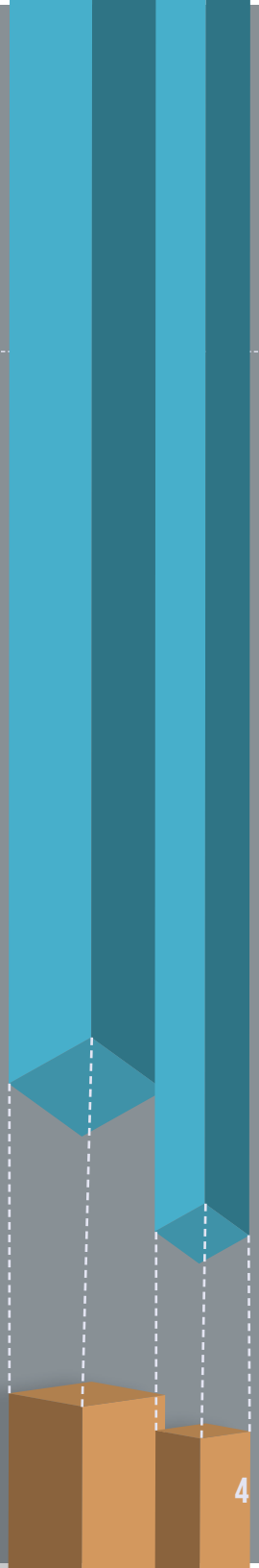
METHODOLOGY

Creating a standardized/simplified simulation using a software called Anylogic to determine the efficiency of building circulation, time of arrival (TOA) and length of stay (LOS) statistics. Anylogic is a simulation modelling tool that supports agent-based and system dynamics simulation methods for business applications, planning and architecture. Using these tools, I can compare the results from existing and theoretical designs, both traditional and modular. Alongside these simulations, a correlational study will be completed to measure cost estimate, energy use and quality of life analytics. To address any construction concerns I plan to meet with firms that are experienced in modular design as well as manufacturers in modular design. Following the completion of this research, I will develop a design solution(s) that creatively rectifies any design flaws that prohibit the most efficacious functionality.

OBJECTIVES IN ANYLOGIC

- Develope a model using a replicable process for an array of ambulatory clinics
- Measure Pedestrian Flow Statistics
- Measure TIme of Arrival Statistics
- Measure Length of Stay Statistics
- Use correlation tactics to compare clinics of different construction types

AnyLogic 8.8.1 Logo (https://www.anylogic.com/)

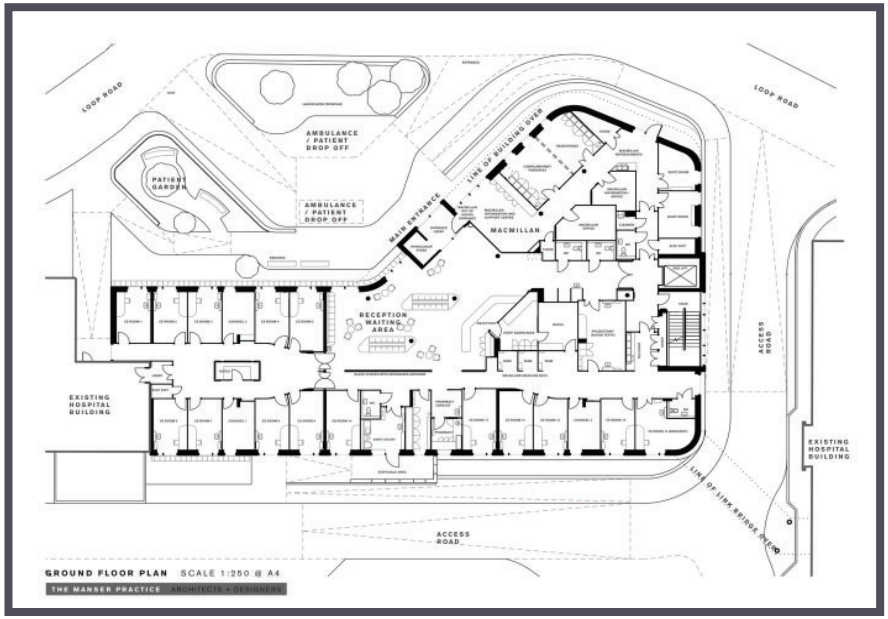


CORRELATIONAL STUDY:

NGS MACMILLAN UNIT | CHESTERFIELD, UK

PROJECT DESCRIPTION:

YEAR:	2017
ARCHITECT:	The Manser Practice
LOCATION:	Chesterfield, UK
BUSINESS UNIT:	Healthcare
PHOTOGRAPHS:	Hufton + Crow
AWARDS:	RIBA East Midlands Building of the Year
CONSTRUCTION:	Traditional (£ 10m)
SIZE:	2,140 SQ. M.



WHY THIS PROJECT?

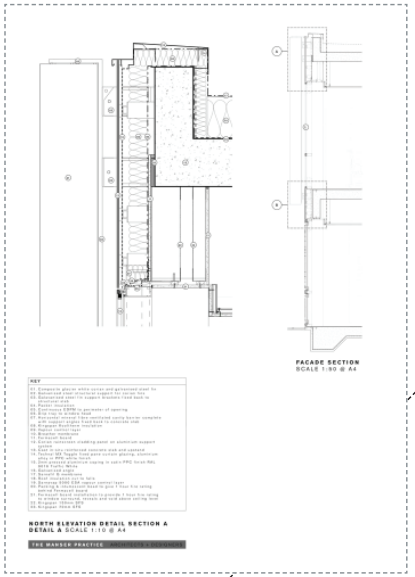
The NGS Macmillan Unit is a standard ambulatory care facility constructed as an addition to the Chesterfield Royal Hospital. Its services, professionals, scale and typology are a perfect example of a clinic that had the opportunity to use prefabricated construction methods. Its unique spatial organization and envilope are a great representation of the possabilities provided by traditional construction. Reaching the limits of an organic facade while maintaining high efficiency, it is the perfect sample to be tested.

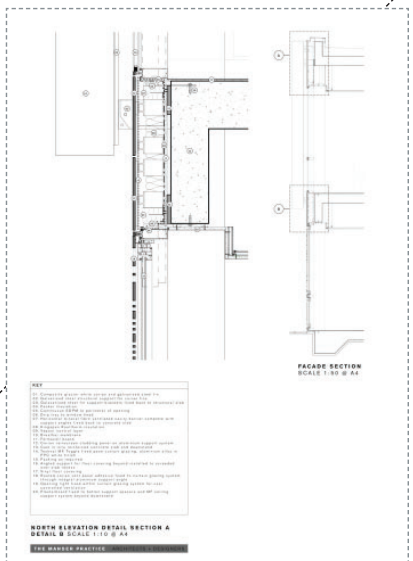
Access to Information

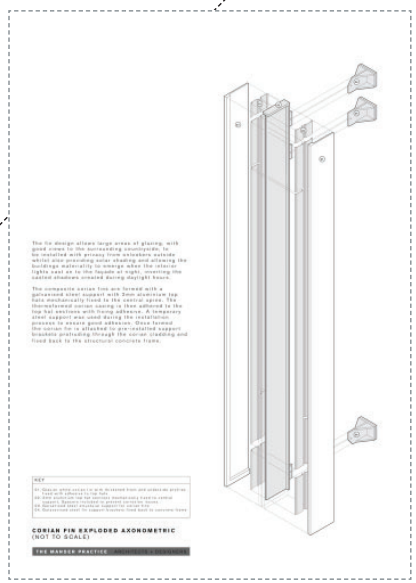
The NGS Macmillan Unit has readily available research and drawings for study. While it would beneficial to visit this site in person, I have found it unnecessary due to the bountiful amount of information that can be found online.

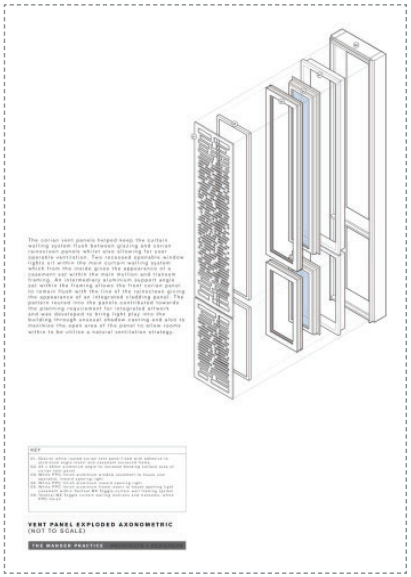
Materiality

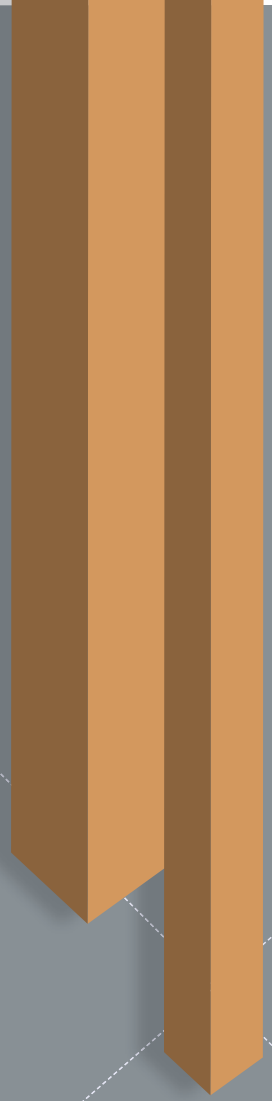
Healthcare facilities require an abundance of specific materials to maintain a sterile environment, provide safe passage and avoid contamination from units such as labs and xray's. These are standardized and universal materials, however, the facade has more creative freedom as seen in the details. This would provide a challenge to create a design solution that not only functions properly internally but also contains the dynamic aesthetic of its envilope.











ANYLOGIC

SIMULATION START

SPATIAL ORGANIZATION

- EXAM ROOM/IN USE
- NURSE (RESOURCE)
- DOCTOR (RESOURCE)
- PA (RESOURCE
- LAB
- ENTRANCE
- EXIT
- EXISTING/UNACCESSABLE

CAPACITY

RegisteredNurse
39%
18/18

ExamRoom
65%
14/15

Doctor
69%
1/2

Lab
17%
2/2

LabTechnician
23%
2/2

PhysiciansAssistant
68%
3/4

UNDERSTANDING THE "GUI"

Graphical User Interface (GUI) references the operating system used to manage the simulation's interactions. In this image, the entire layout of the model is presented in the running simulation. Here the user can see:

1. The constructed model (Room Boundaries)
2. Visualized - automatically updated statistics (Graphs)
3. Model manipulation tools (buttons and sliders)
4. The Process Model (Logic tree)
5. Agent interaction

Healthcare design must be appropriate for any and every user group including, disability, foreign visitor/speaking individuals (members of a group who do not speak English), audibly/visibly impaired and now including members of rural communities. This design must accommodate medical professionals (Doctors, Surgeons, Radiologists, nurses, receptionist, janitorial staff, etc.) patients and victims of illness, mental and physical injury/disease.

RECEPTIONIST PATIENT NURSE (RN) DOCTOR PA LAB TECHNICIAN

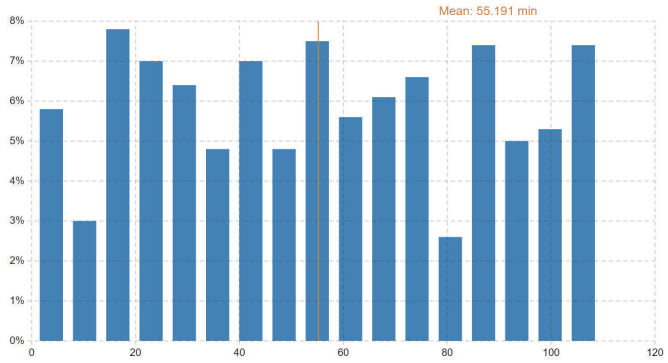
UNDERSTANDING AGENTS

Agents as represented above are the "living" entities within an AnyLogic model. Their appearance and actions can be defined individually or as a population - this is how they fulfill their roles. The listed agents in this model were specifically chosen as the core/ control agents to be used in the replicable model.

PROFESSIONALS	
Physician (MD/DO)	*Doctors diagnose and treat illness and injury or provide referals for unique treatment.*
Physician Assistant (PA)	*Provides direct patient care diagnosing and treating minor illness and conduct minor procedures.*
Registered Nurse (RN)	*Provide and coordinate patient care and educate patients about health management.*
Lab Technician	*Prepare samples for analysis and conduct tests on biological samples.*
Receptionist	*Welcomes, directs and serves visitors upon arrival as well as over-the-phone directory.*

PROCESS LOGIC - MAIN

The logic or block code of the simulation is displayed below. Here is where the order of operations is defined. The goal of this logic network was to establish a core/generic tree that can be replicated to other models. The produced results will be the control variable for the proposed modular structure designed using similar spatial organization.



LENGTH OF STAY

Measures the patients Length of Stay at the clinic from the first data collection node at the start of the process to the second data collection node once the patient reaches the exit door.

Results:
Day - 51.088 min.
Week - 52.061 min.
Month - 55.191 min

Data collection node start {Length of Stay} (used for multiple tables)

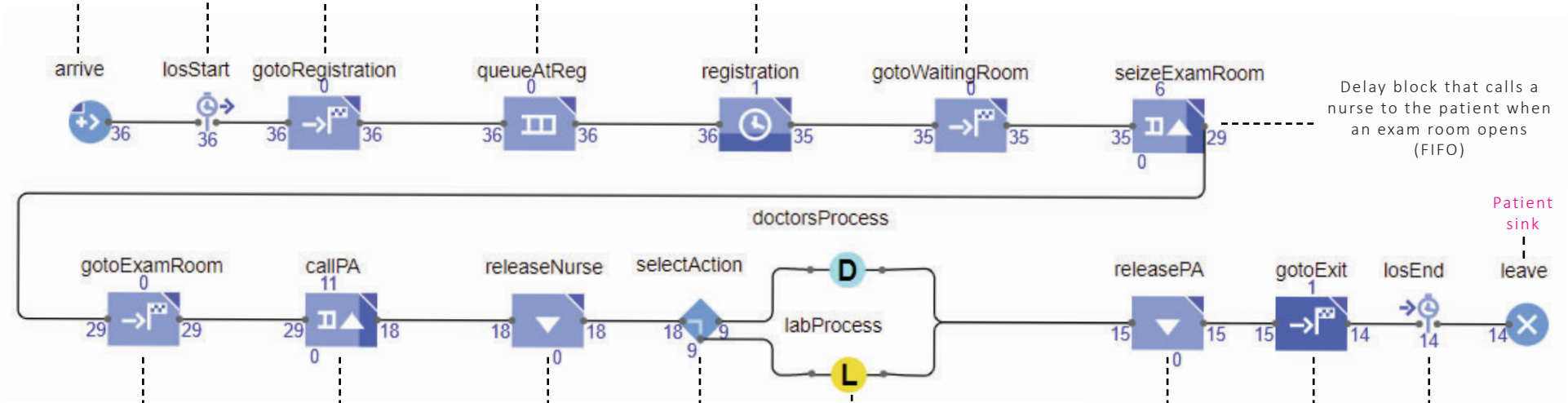
Source node for the # of patients that arrive

# of patients that arrive at the reception desk

Defined waiting line if the reception desk node is full

Delay period that represents the variable "avg. registration time"

on registration end # of patients waiting to be seen by a nurse



Delay block that calls a nurse to the patient when an exam room opens (FIFO)

Patient sink

Patient, nurse and exam room meet - # of patients

After specified exam time - nurse calls a PA from resource pool to patient in exam room

PA takes over remaining exam prompting release nurse

# of patients proceeding to the lab, doctor or new agent 0.5/0.5 probability

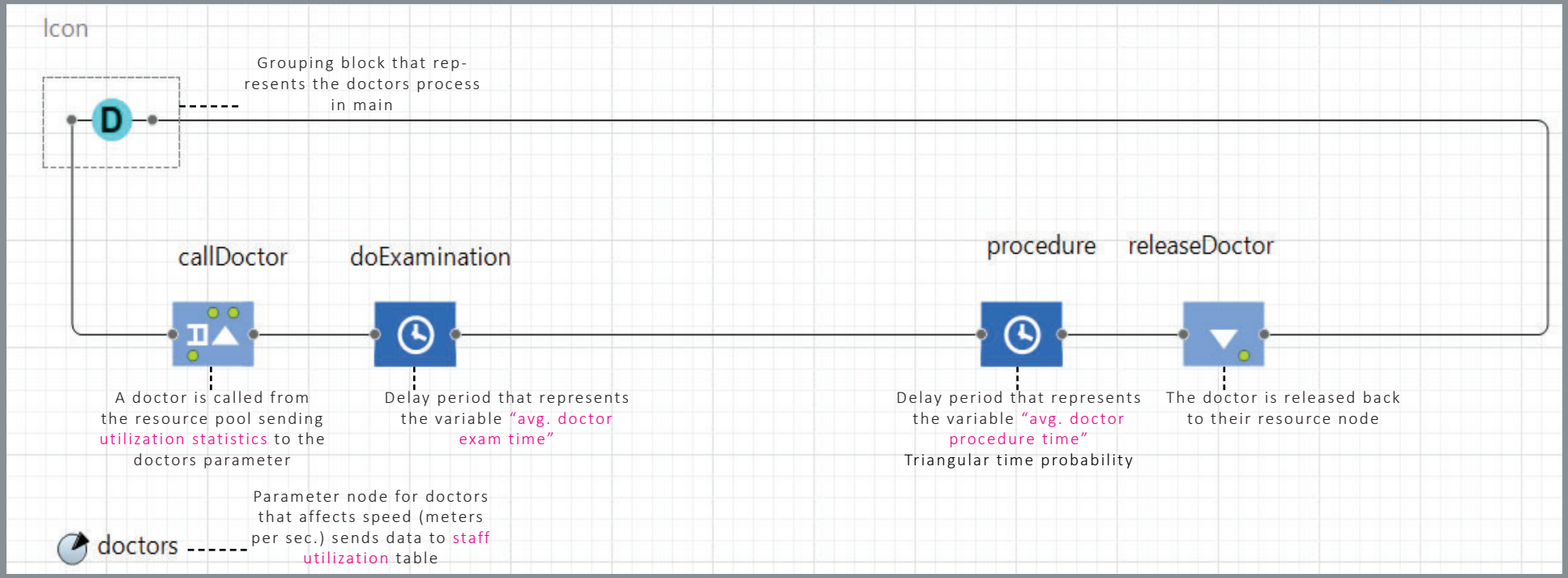
Process nodes are defined by a seperate hidden network

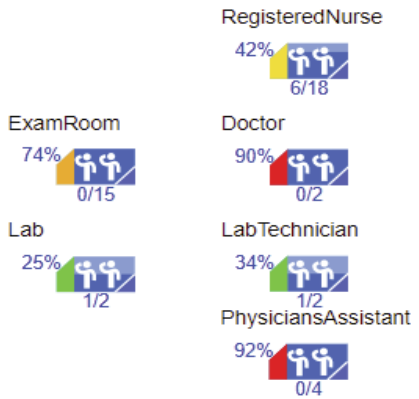
The PA is then released back to their resource pool

# of outpa- tients exiting the simulation

Data collection node end {Length of Stay} (used for multiple

DOCTORS PROCESS



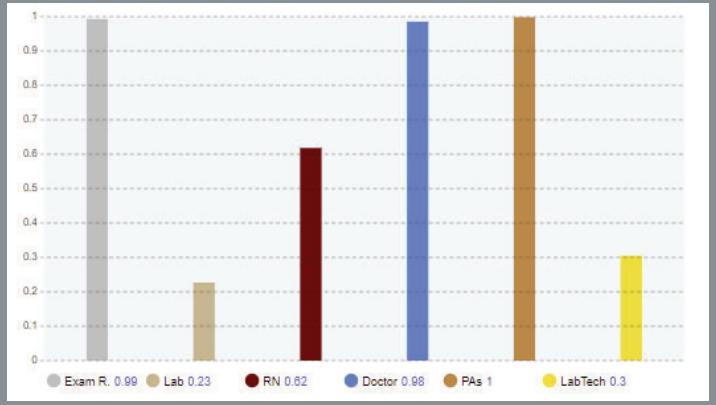


RESOURCE BLOCK

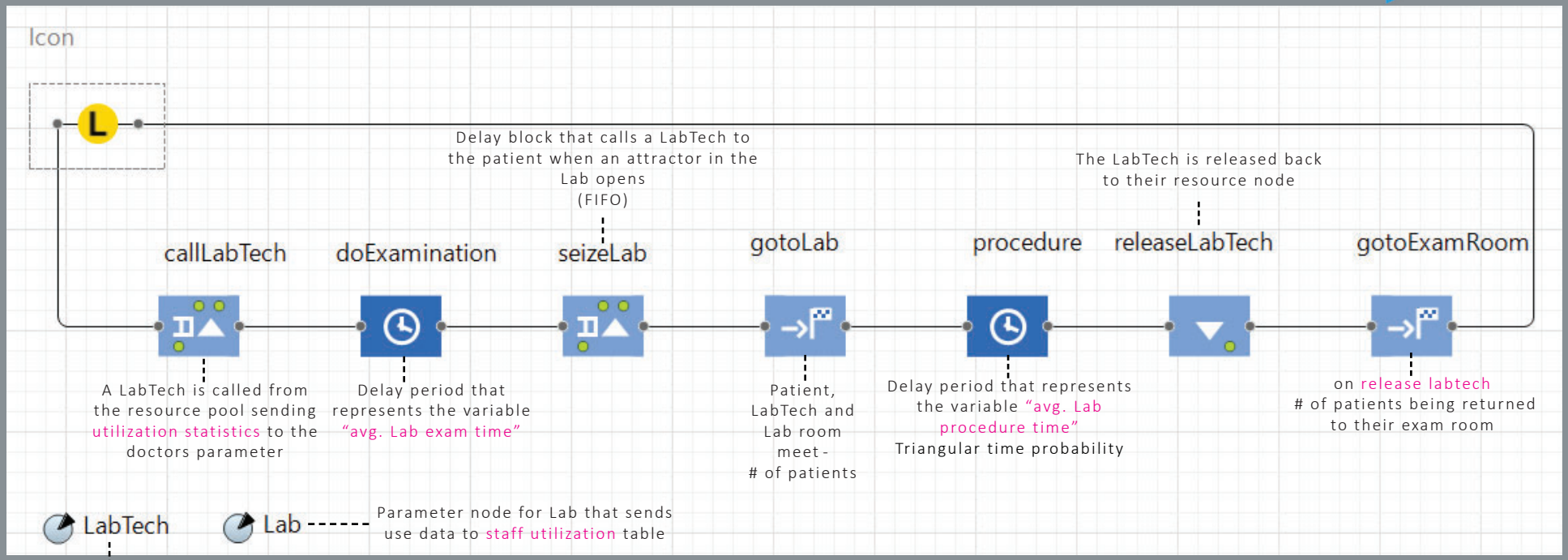
Resource blocks are grouping nodes that represent a resource pool of a particular agent. In this case the Doctor resource block is being utilized to seize an exam room, perform an exam, perform a procedure and then return to its resource node within the model. Resource blocks can work with data sets to visualize statistics. Their capacity and tasks can be altered using parameter nodes as well as interactive tools such as sliders or buttons.

STAFF UTILIZATION

The staff utilization table measures the percent usage of a particular agent. This variable is measured through agent parameters as seen above, sending the information to this table using the logic ExamRoom.utlization() for example. The importance of this data set is to ensure continuity among different simulations. The baseline mean should be replicated to test the logic network for errors.

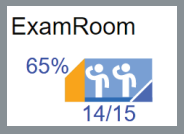


LAB PROCESS



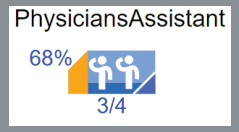
Parameter node for Lab Technicians that affects speed (meters per sec.) sends data to staff utilization table

RESOURCE BLOCKS



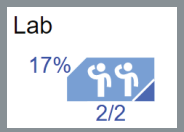
NODES:

callLabTech
gotoExamRoom



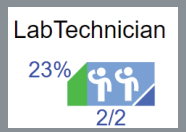
NODES:

doExamination
seizeLab
gotoExamRoom



NODES:

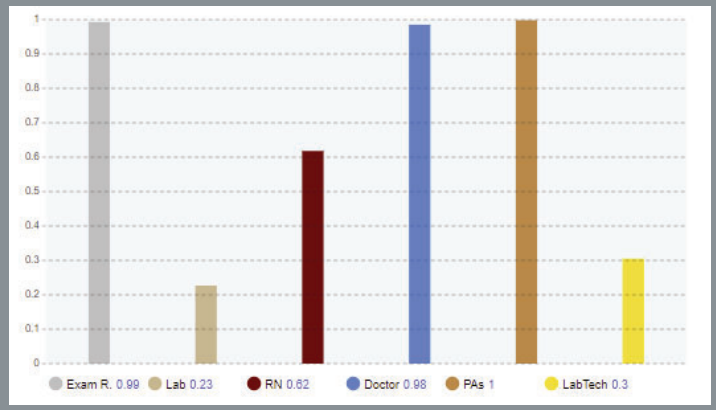
seizeLab
gotoLab
procedure



NODES:

callLabTech
doExamination
seizeLab
gotoLab
procedure
releaseLabTech

STAFF UTILIZATION



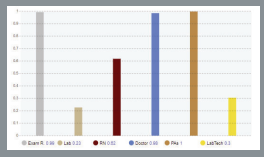
The staff utilization table measures the percent usage of a particular agent. These variables should remain relatively the same across every seperately run simulation. Variables change with arrival rate parameters.

RESULTS

Having completed a fully functional model that measures Pedestrian Flow/Time of Arrival statistics, Length of Stay statistics and have completed the preliminary research on Cost estimation, Energy modelling, materiality and quality of life analytics (based on subjective accounts) further studies can be conducted in comparing the efficacy of modular versus traditional construction.

The baseline results from the AnyLogic model are displayed below as an average or accompanied by a visual aid:

UTILIZATION RESULTS (6.2 AR):

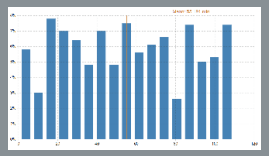


FULL LENGTH ETA (N/S) (6.2 AR):
Distance (m) - 16
ETA (sec.) - 22.4

FULL LENGTH ETA (E/W) (6.2 AR):
Distance (m) - 51.52
ETA (sec.) - 78.128

EXAM ROOM UTILIZATION (6.2 AR):
Day - 73 Units
Week - 518 Units
Month (30 Days) - 2129 Units

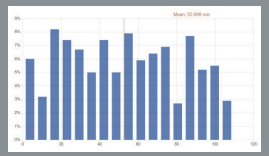
DOCTOR UTILIZATION (6.2 AR):
Patients per hour - 25.55



LENGTH OF STAY RESULTS (6.2 AR):
Day - 51.088 min.
Week - 52.061 min.
Month - 55.191 min

LAB UTILIZATION (6.2 AR):
Day - 17 Units
Week - 120 Units
Month (30 Days) - 490 Units

PA UTILIZATION (6.2 AR):
Patients per hour - 36.5



LENGTH OF STAY RESULTS (6.5):
Day - 52.646 min.
Week - 52.989 min.
Month - 57.300 min

REGISTERED NURSE UTILIZATION (6.2 AR):
patients per hour - 2.24

LABTECH UTILIZATION (6.2 AR):
Patients per hour - 10.95

CONCLUSION

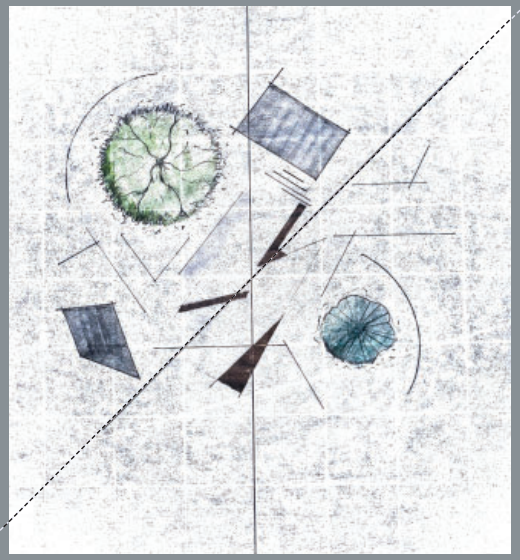
The AnyLogic pedestrian model functions smoothly with similar results upon every simulation end. The ultimate goal for this model is to be able to replicate its processes on other envrionments. Having gathered all of the necessary data for the control environment, the NGS Macmillan Unit, this will be possible. The necessary variables needed to be studied grows as my research progresses. One of the expected new measurements will be material handling within the environment. This will add a more realistic depth to the models results.

There are many moving parts and tasks involved in an ambulatory care unit. To produce more realistic results, new agents will have to be added to the network. The projected additional agents will include:

- Nurse Practicioner
- Xray
- Xray Technician
- Medical Assistant
- Receptionist
- Janitorial Staff

LIMITATIONS

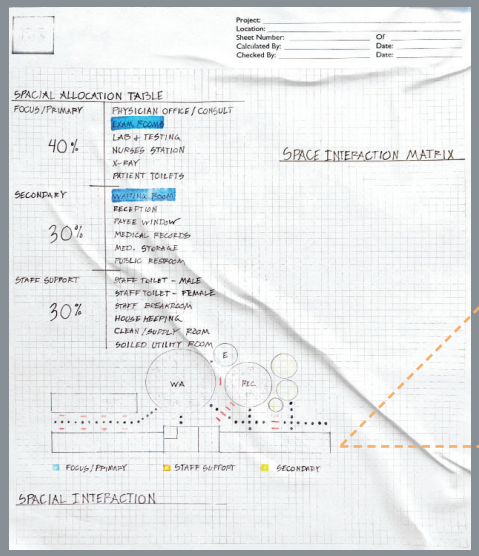
The abundance of case studies, both physically and in literature cannot all be addressed. I am choosing to not observe more than the selected representative samples in order to allow more depth of understanding regarding the efficacy of the project in which I will focus.

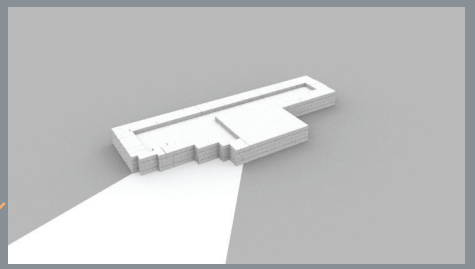


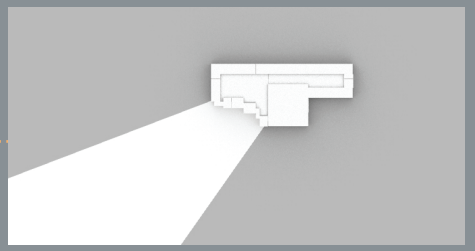
PROJECTIONS

Phase II in the spring semester is when the design solution is produced. In order to confidently rectify any issues stated in my research, I will need a larger sample group for both the traditional and modular samples. This way the spectrum is lengthened and the results are more accurate. Populating new case studies using the process network I have created alongside the newly added components will produce sound results.

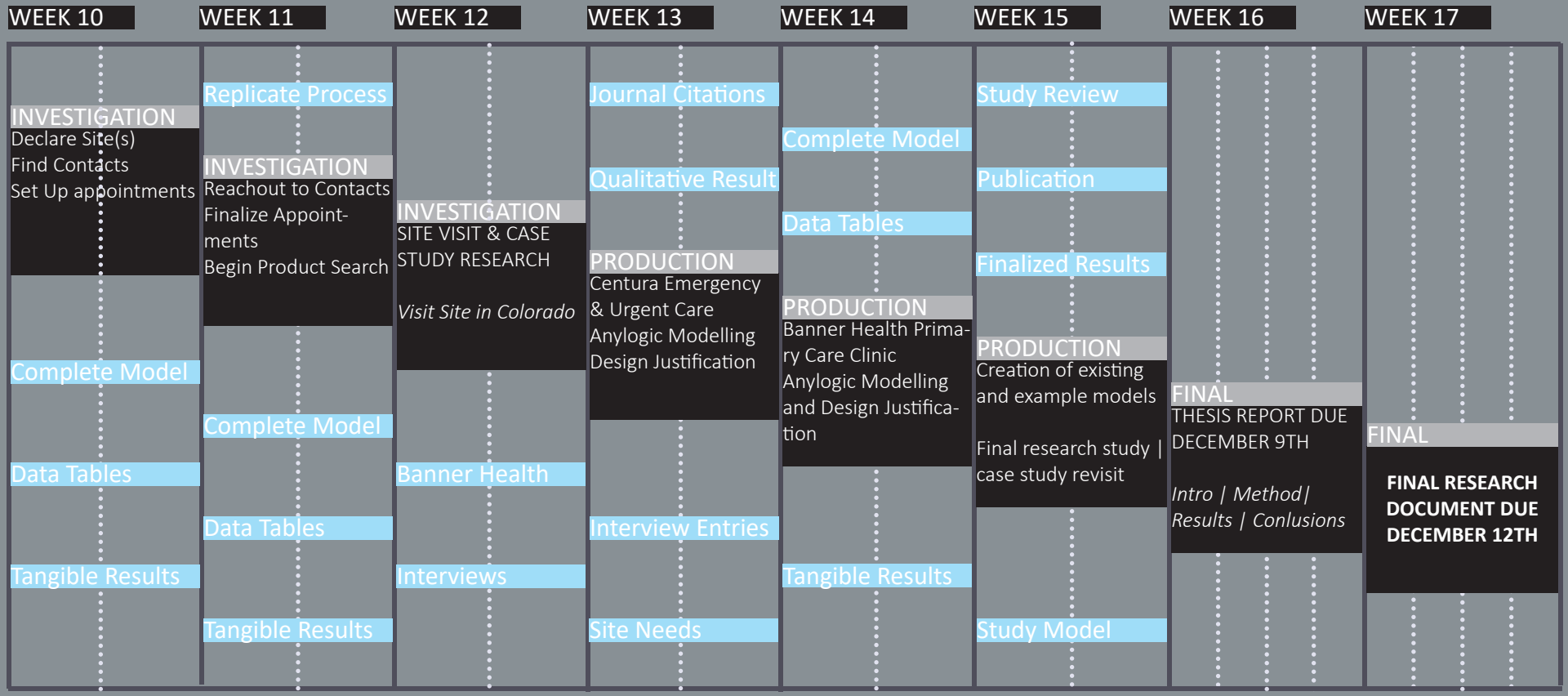
The goal of Phase II is to echo the spatial organization of a samples counterpart to determine which process functions the best.







FALL RESEARCH SCHEDULE:



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WORKS CITED

/author/elizabeth-Evitts-Dickinson. "Rethinking the E.R.: Hospital Emergency Department Plans." Architect, 5 Apr. 2007, https://www.architectmagazine.com/design/buildings/rethinking-the-e-r-hospital-emergency-department-plans_o.

Channel, M. "Download Doctor Consulting Patient for Free." Vecteezy, Vecteezy, 21 July 2020, https://www.vecteezy.com/photo/1226780-doctor-consulting-patient.

Harrouk, Christele. "WZMH Architects Designs Smart Screening and Testing Pod for Covid-19." ArchDaily, ArchDaily, 17 June 2020, https://www.archdaily.com/941878/wzmh-architects-designs-smart-screening-and-testing-pod-for-covid-19.
"Modular Healthcare Facility - Micro-Hospital." Ellis Modular, 8 June 2022, https://www.ellismodular.com/facility-types/healthcare/hf10710-a/.

"The New Stanford Hospital." Inhabitat, 4 May 2011, https://inhabitat.com/rafael-vinolys-new-stanford-hospital-design-features-modular-daylight-filled-cubes/the-new-stanford-hospital-7/.

"Prefab Hospital: How We Built a Modular Hospital in under 9 Months ." MECART Cleanrooms, 19 Sept. 2022, https://www.mecart-cleanrooms.com/projects/case-studies/prefab-modular-hospital/.

Shinkman, Ron. "Prefab Saved $4.3 Million on Denver Hospital Construction." Fierce Healthcare, 18 Dec. 2014, https://www.fiercehealthcare.com/finance/prefab-saved-4-3-million-denver-hospital-construction.

"Stanford Hospital - Kieran McCAUGHEY." Cargo, https://cargocollective.com/kieran/STANFORD-HOSPITAL.
team, Code8. "Ngs Macmillan Unit." The Manser Practice, 3 Mar. 2021, https://www.manser.co.uk/project/nhs-macmillian/.

Award-winning Modular Construction. Triumph Modular. (2022, July 21). Retrieved September 21, 2022, from https://www.triumphmodular.com/about-triumph/awards/

Emagine. (2021, October 5). *Global Architecture, Engineering & Design Firm.* CannonDesign. Retrieved September 21, 2022, from https://www.cannondesign.com/

Modular construction: Despite benefits, healthcare adoption is slow. Facilitiesnet. (2020, October 5). Retrieved September 21, 2022, from https://www.facilitiesnet.com/healthcarefacilities/article/Modular-Construction-Despite-Benefits-Healthcare-Adoption-Is-Slow--18981

Prefab Hospital: How we built a Modular Hospital in under 9 months . MECART Cleanrooms. (2022, September 19). Retrieved September 21, 2022, from https://www.mecart-cleanrooms.com/projects/case-studies/prefab-modular-hospital/

Prefabrication and modular construction 2020. www.construction.com. (2020, September 29). Retrieved September 21, 2022, from https://www.construction.com/toolkit/reports/prefabrication-modular-construction-2020

Simulation modeling software tools & solutions for business. AnyLogic. (n.d.). Retrieved September 21, 2022, from https://www.anylogic.com/

Why the healthcare industry is embracing modular construction. BOXX Modular. (n.d.). Retrieved September 21, 2022, from https://www.boxxmodular.com/resources/blog/why-the-healthcare-industry-is-embracing-modular-construction/

Zevely, A. J. (2020, August 6). *San Diego Company converts shipping containers into covid-19 'Quik Labs'*. cbs8.com. Retrieved September 21, 2022, from https://www.cbs8.com/article/news/local/zevely-zone/covid-19-quick-labs-mobile-rapid-testing-san-diego-company-tpt-med-tech/509-b95f718d-6186-4c16-a26f-a5db70e8876a