THE EFFICACY OF MODULAR DESIGN IN HEALTHCARE

THE EXPLORATION OF MODULAR DESIGN IN HEALTHCARE THROUGH THE COMPARATIVE ANALYSIS OF A TRADITIONALLY CONSTRUCTED HOSPITAL AND ITS MODULAR TWIN

Figure 01 | page 1, Structural Connections, render | daniel heckmann

THE EFFICACY OF MODULAR DESIGN IN HEALTHCARE

A DESIGN THESIS SUBMITTED TO THE DEPARTMENT OF ARCHITECTURE AND LANDSCAPE ARCHITECTURE OF NORTH DAKOTA STATE UNIVERSITY

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ABSTRACT

Modular design has become an industry leading philosophy for the future of community-based health services. Modular construction 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, minimal impact, re-use, and modification. This process contradicts traditional construction, pre-fabricating spaces off site to be assembled later. Through correlational research and simulation software, products of modular and traditional construction methods can be compared using operational statistics.

The modular approach to healthcare construction has potential to save lives and reduce the risk of patient discomfort. Utilizing these design principles to codify the inherent responsibility of modern healthcare. The purpose of this thesis is to study the efficacy of the current method of modularity among the industry with intention to refine the process for a safer, enjoyable, more efficient, and replicable solution.

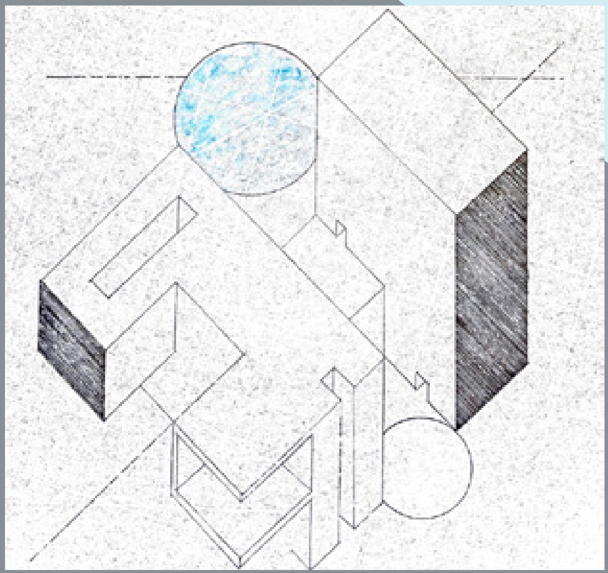


Figure 02 | page 6, modular deconstructivism, illustration | daniel heckmann

RISE MODULAR

My inspiration for this topic came from Rise Modular in Owatanna, Minnesota. A Modular manufacturing plant I was fortunate to visit during my summer internship. During our tour, I was able to physically experience the prefabrication of building mods through an experimental process I was told to remain secret. I had previous knowledge on Modular design but had little interest in it because of the assumption that such a fixed methodology would arrest creativity and was exclusive to residential and hotel design.

I have always held a great interest in healthcare architecture. The ability to create a safe place intended for healing the most vulnerable of people is admirable. So, when the lightbulb went off in my head I was excited. I understood what I was seeing in front of me wasn't meant for hospitals, but could it be?

OWATANNA, MINNESOTA

Figure 03 | RISE Module Crane, Figure 04 | RISE Module Assembly

ALVERA APARTMENTS` - MODULAR MULTIFAMILY

The second half of our tour, we were presented with Rise's project portfolio. The Alvera Apartments in St. Paul was the jewel of their work. A one-of-a-kind structure reaching 5 stories high in stacked modular units, sheared to a sharp point and vibrant in color. This was my first experience with a modular building that felt permanent.

Figure 05 | Alvera Apartments

DYNAMIC

Later that summer, I revisited the anomalous structure and began my research to determine the limits of such a misunderstood method of design.

Figure 06 | Dynamic Alvera Apartments

NARRATIVE

In practice, the study, and design of **Healthcare Architecture**; 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 occupancy of hospitals are determined by the standard daily limit of a unit's typology. When a public health crisis occurs, this leaves hospitals without proper facilities for the influx of patient care. The first solution is expansion, often times in the form of permanent construction with the risk of vacancy when the crisis subsides. The sudden unbalance of supply and demand fuels the risk of **panic-architecture**. A fast paced solution to a problem with a high likelihood of error and often times patient discomfort results. The **Modular Twin** to the NGS Macmillan Unit proposes an idea that expansion is still achievable without the need for panic, discomfort, or waste. Modular architecture is not a new development in the field. Originally intended for residential design, It has expanded its purpose on a commercial scale.

Lowering the time of construction, design development and planning, efficient growth is achievable in emergencies like the pandemic. In the process, architects will be tasked with designing these mods, similar to a product patent that can be later repurposed to continue its line for expansion. The on-site construction is reduced to a short assembly with little noise and environmental pollution. Patients in attendance during these times will be subjected to less stressful situations and noise which will ultimately promote **recovery**.

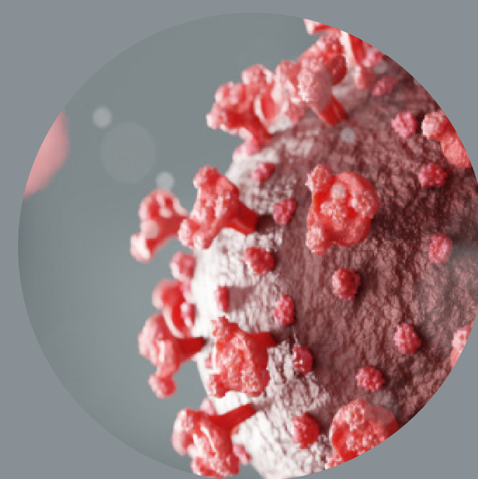


Figure 07 | COVID-19

PROJECT TYPOLOGY:

The proposed design will be a cancer treatment & outpatient healthcare center.

MODULAR: Preconstructed units tailored to the specifications of the healthcare industry, professionals and patients alike.

EFFICIENT: Consciously organizing spaces that indirectly and directly affect societal needs, engagement, functionality and circulation.

ADAPTIVE: A solution that is modifiable, replicable and can be repurposed.

REFINED: A design that rectifies past mistakes and proposes new solutions.

ACCESSIBLE: Geographically and internally reachable and welcoming.

The proposed project typology will include cancer treatment, outpatient services, laboratory testing, health consultation and more.

Figure 08 | Emergency Care

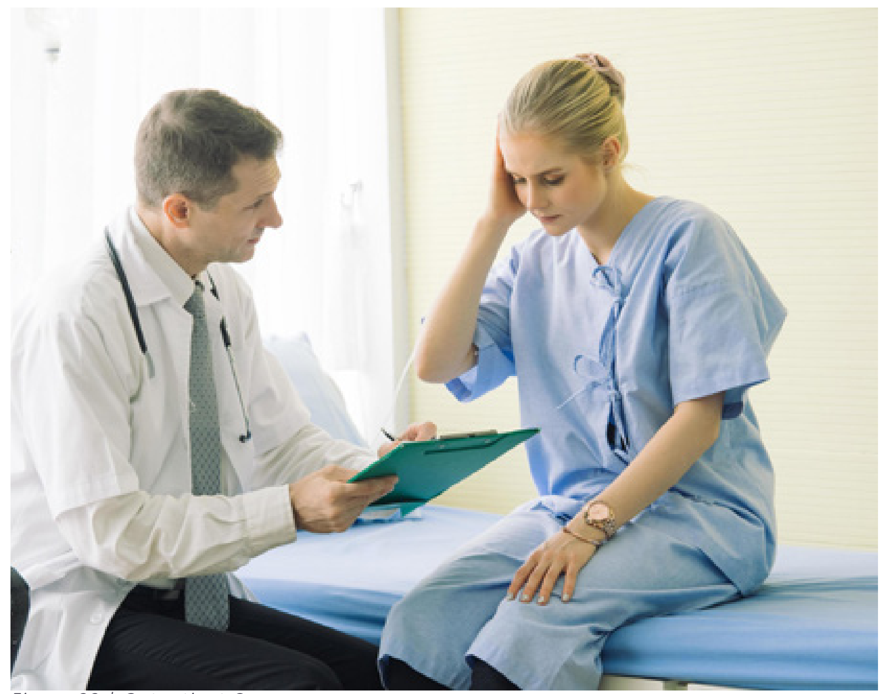


Figure 09 | Outpatient Care

PROJECT TYPOLOGY:

An outpatient healthcare center provides efficient medical aid to the community it attends to. It is a compact business unit composed of standardized room layouts as a product of modern technology and research. The unit modules often serve more than one purpose to allow for efficient circulation and shorter outpatient care. Patients attending this space will have the opportunity to receive aid from state-of-the-art medical utilities and professionals in a smaller fast-paced environment. This architectural typology is ideal for modular design because of its existing formula for spatial layout with the only juxtaposition being circulation amongst units.

Figure 10 | Lab Testing


Figure 11 | Healthcare Consulation

PROJECT JUSTIFICATION:

With sustainability becoming a globally recognized responsibility, every professional field has started to evolve, experimenting with different approaches to prevent the previously inevitable. It is imperative that these experiments produce sound conclusions that not only arrest the ecological damages of their predecessors but maintain their functionality and purpose. Modular architecture as a means of healthcare design is still in its infancy, experimentation that is accompanied by great promise. Examining the efficacy of these designs through circulation and functionality is necessary for those promises to come true.

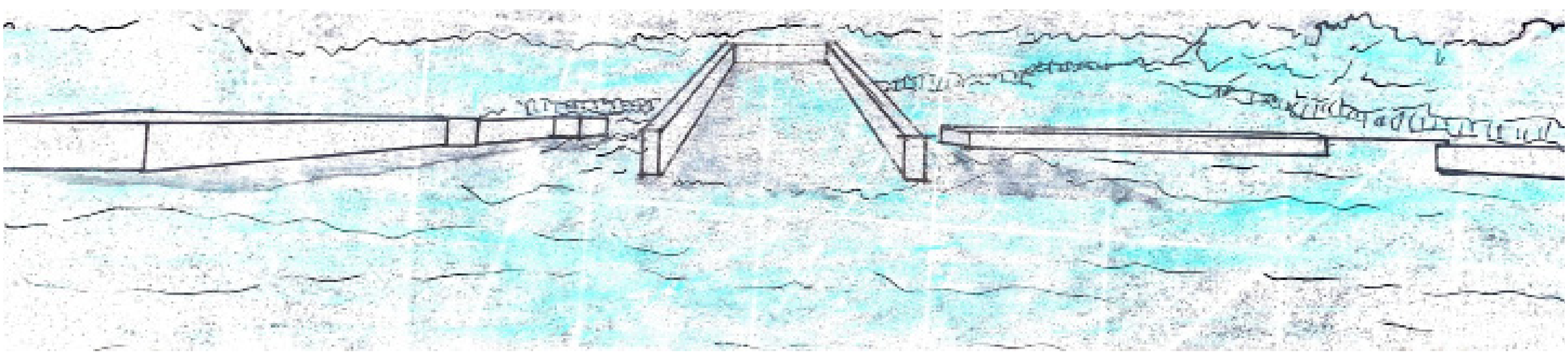


Figure 12 | Sustainability, illustration | daniel heckmann

PROJECT EMPHASIS:

EFFICACY

The underlying objective of this thesis is to simulate & analyze the efficacy of modular design in healthcare. This includes but is not limited to the following areas of emphasis.

CIRCULATION

Analyzing the circulation of modular units proposed as design solutions to spatial organization in the case study to determine if they are safe, efficient, adaptive, and replicable.

ADAPTIVE RE-USE

Replicating the process of current modular healthcare design, refining the process to see if this design methodology is applica-ble in other contexts.

COMPARATIVE ANALYSIS

Comparing the modular designs with traditional examples to understand the benefits and missing components there might be so that they may be addressed in the proposed project solution.

MODULAR
REFINED
ANALYTICAL
CIRCULATION
ADAPTIVE
REUSABLE
INNOVATIVE
EFFICIENT
ACCESSIBLE
WELCOMING
COST EFFECTIVE
MATERIALITY
SAFE
CREATIVE
FUNCTIONAL
SUSTAINABLE
CLEAN
REALISTIC
COMMUNAL
INTENTIONAL

MAJOR PROJECT ELEMENTS:

PROPOSED SPATIAL USE

PRIMARY

SECONDARY

TERTIARY

PROPOSED SPATIAL PROGRAM

GENERAL PATIENT CARE

- Physician Office/Consult
- Exam Rooms
- Lab & Testing Center
- Nurses Station
- X-Ray Station
- Patient Toilets

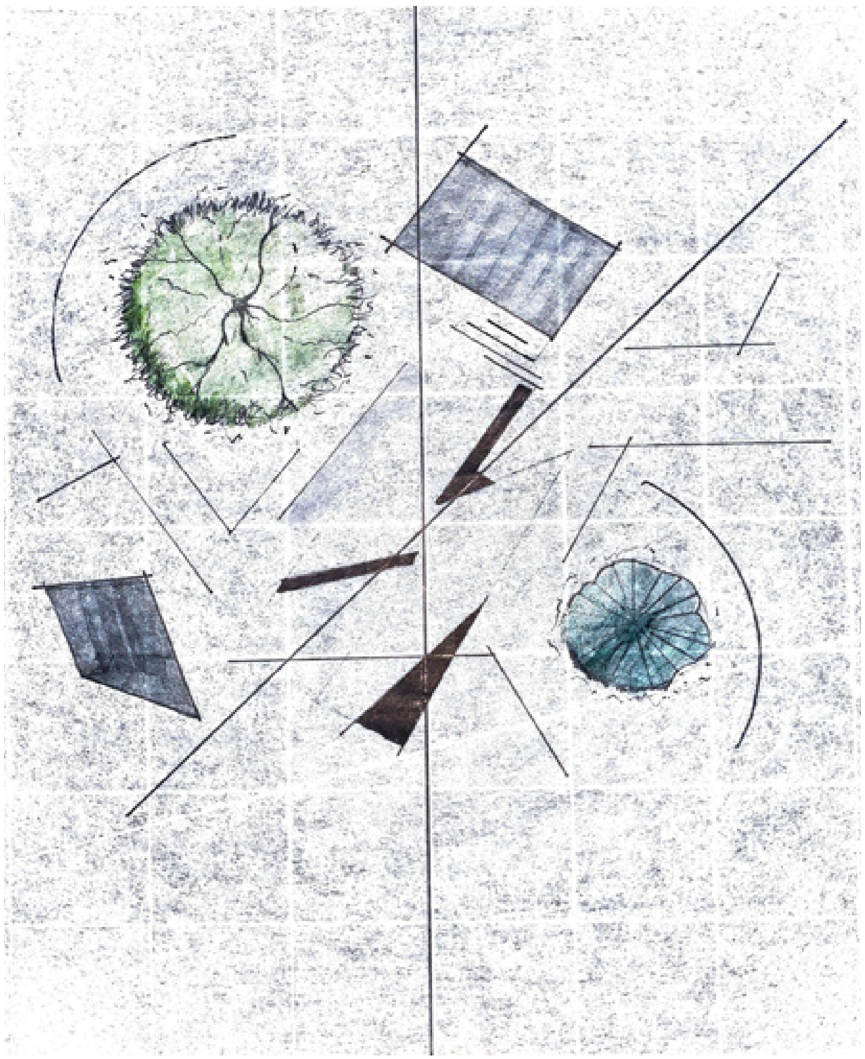
ENTRY LOBBY & RECEPTION

- Waiting Room
- Reception
- Payee Window
- Medical Records
- Medication Storage
- Public Bathroom

STAFF SUPPORT SPACES

- Staff Toilet (Male)
- Staff Toilet (Female)
- Staff Break Room
- Housekeeping
- Clean/Supply Room
- Soiled Utility Room

MAJOR PROJECT ELEMENTS



	CUTTING EDGE:	REIMAGINED DESIGN
	QUALITY OF LIFE:	ENJOYABLE & CREATIVE
	FAST-PACED:	EFFICIENT & SAFE
	RENEWABLE:	SUSTAINABLE
M.E.A.R.A	STANDARDIZED:	GUIDED BY PRINCIPLES

Figure 13 | Abstract Elements, illustration | daniel heckmann

CLIENT & USER DESCRIPTION:

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 as described above and victims of illness, mental and physical injury/disease.

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.*
Nurse Practicioner	*Licensed health care clinicians who manage patients health conditions and treatments.*
Registered Nurse (RN)	*Provide and coordinate patient care and educate patients about health management.*
X-Ray Technician	*Perform medical examinations using an X-ray.*
Medical Assistant	*Conduct basic lab tests, sterilize medical instruments and dispose of biological and hazardous waste.*
Lab Technician	*Prepare samples for analysis and conduct tests on biological samples.*
Medical Secretary	*Schedule appointments, patient billing and record medical charts.*
Medical Transcriptionist	*Review and edit medical documents and record patient/professional visits.*
Receptionist	*Welcomes, directs and serves visitors upon arrival as well as over-the-phone directory.*
Janitorial Staff	*Responsible for the highest standard of cleaning and sterilization of the clinic's public spaces.*
Administration	*Including management, human resources and corporate titles.*

Figure 14 | High Traffic Emergency Clinic

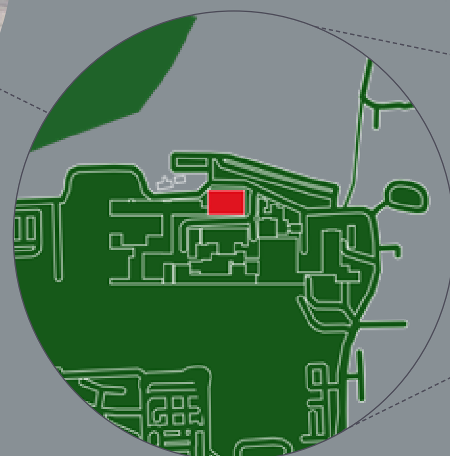
LOCATION

THE NGS MACMILLAN UNIT AT THE CHESTERFIELD ROYAL HOSPITAL

CALOW, ENGLAND - 53.2363° N, 1.3980° W

CURRENT UNIT

EXISTING SITE



EXPANDED SITE

Figure 15 | Existing Site

Figure 16 | Current Unit

Figure 17 | Expanded Site

SITE DESCRIPTION:

The proposed outpatient care clinic will be constructed in Chesterfield, England. The site was chosen stricly based on the unit typology of the case study utilized in my correlational research.

This is the site plan for the NGS Macmillan Unit, an addition to the Chesterfield Royal Hospital in the Calow region in England. Key elements of the building site include a patient garden, elevated by a concrete wall to increase privacy. Waste removal is directly connected with the access road and the second-floor bridge connection to the medical records building. There are two primary connections with the existing units. To the east, the Barnes Warde is responsible for the Emergency Management Unit, Patient Discharge Lounge and the Clinical Decision Unit. Directly where the two units meet is an existing egress staircase and exit. The bridge connection on the second floor meets the medical records building exclusive to faculty and staff but also includes a patient corridor to the Pathology Unit which houses the medical outpatient suite and blood tests.

Parking accommodations are made simple by the existing parking lots, 7a and 7b which are untouched with the addition of the NGS.

CHESTERFIELD, ENGLAND

population: 88,483 (2011 census)

Area: 10.15 sq mi

Region: East Midlands

Median Age: 44.9 (2021 census)

Rural to Urban Population: 98% Urban/2% Rural

Broad Demographic Range (Ethnicity):
81% White
1.9% Asian
1.4% Mixed
0.8% Black
0.4% Other

PROJECT GOALS:

The purpose of this research and design solution is to refine the process of modular design in healthcare for a more efficient and applicable methodology, establish a physical case study that can be later analyzed and replicated and encourage the social acceptance of modular design as a means of public health amongst design professionals, healthcare professionals and patients alike.

Through this process, research and analytical skills will be refined. Design and technical drawing will be practiced at its highest level in acedemia thus far. Programming and graphic design will be studied and practiced to reach a higher skill level in the field. The author will have displayed their prowess in the field of architecture through the fulfillment of these tasks.

Over the course of North Dakota State University's architectural program, the design thesis is the most pensive, technical and experimental assignment offered. The completion of this research and design solution will conclusively define the authors capabilities and passion in the field, foreshadowing their purpose as a designer.

- Identify the similarities, differences, pros and cons of stick-built and modular architecture in the field of healthcare.
- Conduct simulated experiments to gather statistical results.
- Design a sample model (digitally and physically) using the most effective methods from both studies which can be later referenced.
- Educate people on the benefits or flaws within modular design in healthcare

A PLAN FOR PROCEEDING

RESEARCH DIRECTION

DEFINED RESEARCH DIRECTION

The first step in this process is scheduling. The entirety of the project and all of its components will follow a tentative schedule as it permits.

Following the proposal, research is to be conducted through case studies, scholarly articles, site visits, simulations and model experimentation. This diverse set of research mediums allows the information produced to be fully comprehensive and justified.

A site and business unit inventory and analysis will be conducted to organize the information so that it will be later analyzed and published.

From the prior research a design solution will be created guided by the thesis philosophy defined in the abstract.

After the design solution is finalized, graphics, illustrations, models and photographs will be produced for the final thesis presentation explaining the entire process.

DESIGN PROCESS & PRESENTABLES

THESIS PROJECT BOOK

This document will contain the thesis proposal, thesis program, and research report after its conclusion and the final design solution.

PROJECT BOARDS

Graphics, illustrations, photographs and research printed on large presentation boards displaying the process, findings, solution and takeaways.

PHYSICAL MODELS

A series of physical models both hand and laser cut displaying the functionality, scale and design elements of the final solution.

THESIS PRESENTATION

A digital and oral presentation including all aforementioned presentation elements which will narrate the entire process.

METHODOLOGY:

SCOPE

This research will be conducted by a series of simulations using a software called Anylogic to determine the efficiency of building circulation and material handling. 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. To address any construction concerns there will be meetings with firms that are experienced in modular design as well as manufacturers in modular design. Following the completion of this research, a design solution(s) will be developed that creatively rectifies any design flaws that prohibit the most efficacious functionality.

EXPECTED RESULTS

The expectation of this research is to define any complications within modular healthcare design's current configuration and provide ample solutions that can be later studied and utilized in the field. The importance of this research is to provide feedback during the current pioneering era of modular healthcare design. This will ultimately prevent any found design errors from being reproduced.

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 projects in order to allow more depth of understanding regarding the efficacy of the project in which I will focus.

QUANTITATIVE ANALYSIS

ITEMIZE AND ANALYZE RESULTS PRODUCED BY SIMULATION

DEFINE SOLUTIONS TO THE SUBJECT MATTER THAT CAN INFLUENCE THE DESIGN

QUALITATIVE ANALYSIS

DOES THE DATA PRODUCE REFINED SOLUTIONS TO MODULAR DESIGN?

anylogic®

FALL RESEARCH SCHEDULE:

WEEK 10
- INVESTIGATION
  - Declare Site(s)
  - Find Contacts
  - Set Up appointments
- Complete Model
- Data Tables
- Tangible Results

WEEK 11
- Replicate Process
- INVESTIGATION
  - Reachout to Contacts
  - Finalize Appoint-ments
  - Begin Product Search
- Complete Model
- Data Tables
- Tangible Results

WEEK 12
- INVESTIGATION
  - SITE VISIT & CASE STUDY RESEARCH
  - *Visit Site in Colorado*
- Banner Health
- Interviews

WEEK 13
- Journal Citations
- Qualitative Result
- PRODUCTION
  - Centura Emergency & Urgent Care
  - Anylogic Modelling
  - Design Justification
- Interview Entries
- Site Needs

WEEK 14
- Complete Model
- Data Tables
- PRODUCTION
  - Banner Health Prima-ry Care Clinic
  - Anylogic Modelling and Design Justifica-tion
- Tangible Results

WEEK 15
- Study Review
- Publication
- Finalized Results
- PRODUCTION
  - Creation of existing and example models
  - Final research study | case study revisit
- Study Model

WEEK 16
- FINAL
  - THESIS REPORT DUE DECEMBER 9TH
  - *Intro | Method| Results | Conlusions*

WEEK 17
- FINAL
  - **FINAL RESEARCH DOCUMENT DUE DECEMBER 12TH**

Daniel Heckmann

NDSU | Fall 2022

Ganapathy Mahalingam

TYPOLOGICAL RESEARCH

PRECEDENT STUDIES

TYPOLOGICAL RESEARCH:

CASE STUDY: NEW STANFORD HOSPITAL | PALO ALTO, CA

NEW STANFORD HOSPITAL

CASE STUDY

GENERAL PROJECT DESCRIPTION:

YEAR:	2018
FACADE AREA:	300,000 SQ. FT.
LOCATION:	Palo Alto, CA
BUSINESS UNIT:	Education, Healthcare
HEIGHT:	198 FT.
CONSTRUCTION:	Modular
OWNER:	Stanford Hospitals
ARCHITECTS:	Perkins Eastman Architects Rafael Viñoly Architects
ENGINEER:	Nabih Yousseff Associates
AWARDS:	Best Project - Healthcare ENR California, 2020

Figure 20 | New Stanford Overhead

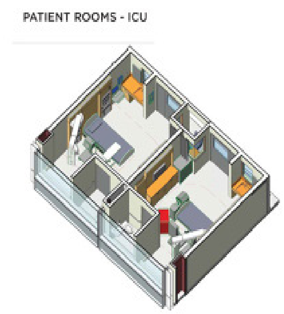


Figure 18| New Stanford Hospital Money Shot

Figure 19| New Stanford Walkway

Figure 21 | New Stanford Unit Layout

NEW STANFORD HOSPITAL
CASE STUDY

SUMMARY
The New Stanford Hospital, while mentioned to be an example of modular construction had a more hybrid approach. Nearly all of the floors are constructed unit by unit, however, there are cascading interior walls, grand curvature and a 12,000 sq f. glazed dome sealing off an open atrium space at its core. The design echoes the architectural context of the university, following the theme of low-rise and horizontal building plans. Large glass cubes define the branches of the hospital, choreographing hundreds of modular units into one cohesive symphony.

PURPOSE
The primary use of this case study was to research the construction methods of a large healthcare structure using modular design as well as find a solution to the twin exterior face's relationship and structural connection issue.

TAKEWAWAYS
Performance was a strict obstacle to tackle considering the exterior faces were glass panelling. The initial proposal called for a sealed gap between the units to omit the need for maintanence. The issue with this was that the design failed to meet thermal perfomance criteria. By introducing a continual low-level positive airflow to the gaps, condensation and maintanence disappeared. The processed air is fed through loops at each floor allowing the benefit of a sealed unit to exist.

Figure 22 | New Stanford Construction

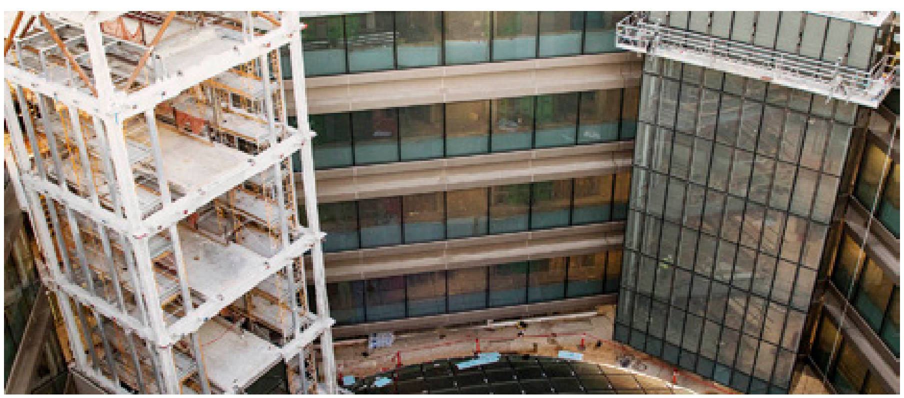


Figure 23 | New Stanford Sketch

TYPOLOGICAL RESEARCH:

CASE STUDY: ELLIS MODULAR | ROCKWALL, TX

Figure 24 | Ellis Modular Logo

Figure 25 | Ellis Modular FP A

Figure 26 | Ellis Modular FP B

Figure 27 | Ellis Modular Phased Build

ELLIS MODULAR

CASE STUDY

COMPANY DESCRIPTION:

YEAR ESTABLISHED:	2012
SERVICE AREA:	Southwest, U.S.
LOCATION:	Rockwall, TX
BUSINESS UNITS:	Healthcare, Education, Agriculture, Energy, Commercial Office, Parks & Rec, Municipal Government, Industrial
PRODUCTS:	Prefabricated Modular Units
SERVICES:	Design-Build and Deployment

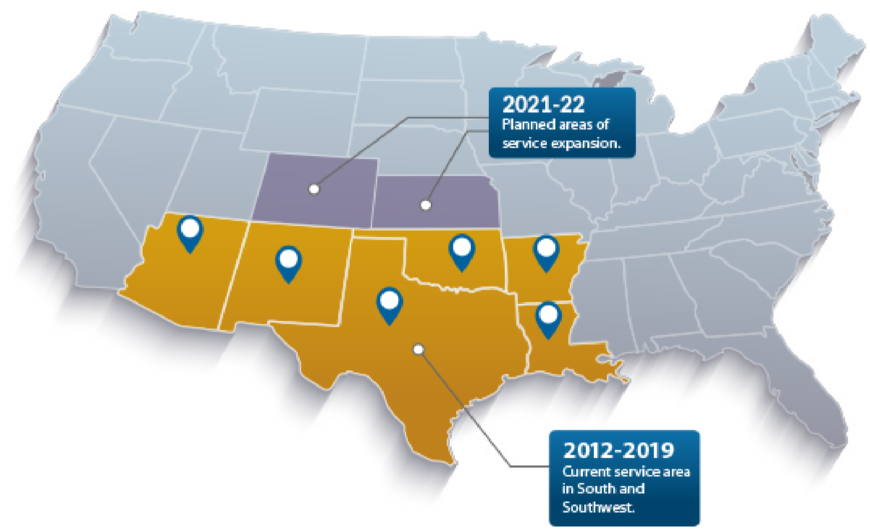


Figure 28 | Ellis Domestic Outreach

ELLIS MODULAR
CASE STUDY

SUMMARY

Ellis Modular is a modular manufacturing company with business units in healthcare, multi-purpose, offices, recreation, education, small project, etc. The most interesting part about their company is their outreach beyond state lines. It is a rare characteristic of a company within modular manufacturing to expand to where Ellis is today. Ellis Modular is a design-build-deploy company with the facilities to collaborate with other firms.

PURPOSE

The purpose of this research was to expand my knowledge on the industry and their methods for manufacturing and transportation.

TAKEWAWAYS

The process of modular construction from design to assembly has many benefits and many obstacles. The current amount of manufacturing-ready factories is slim due to the unpopularity of modular architecture. There is also the issue of project typology. Not every modular manufacturing firm will work with every typology, similar to an architecture firm. Transportation also has its costs and limits. The best approach to modular architecture is to understand your business partner's operations and capabilites. Budget is a commonly noted benefit of modular design, however, without the proper research, projects can reach higher costs than traditional brick and stick construction.

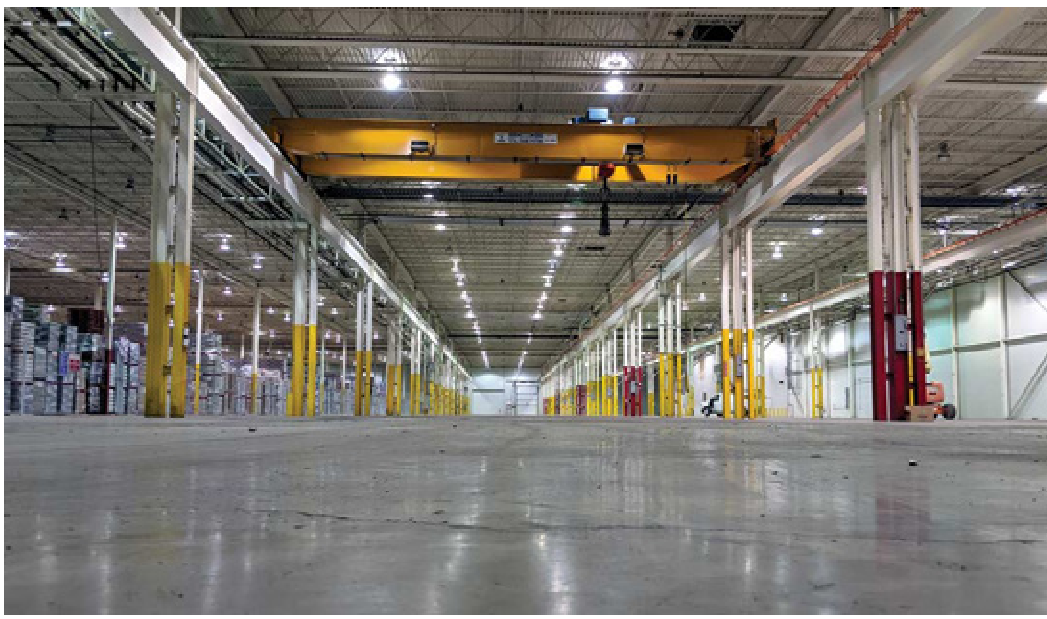


Figure 29 | Ellis Factory

Figure 30 | Ellis Module Crane

TYPOLOGICAL RESEARCH:

CASE STUDY: MAISONNEUVE-ROSEMONT EXPANSION | MONTREAL, CA

Figure 31 | Rosemont Money Shot

Figure 31 | Dual-Pressure Isolation Mod

MAISONNEUVE-ROSEMONT EXPANSION

CASE STUDY

PROJECT DESCRIPTION:

YEAR:	*2024*
ARCHITECT:	*TBD*
MANUFACTURER:	*MECART*
LOCATION:	*Montreal, CA*
BUSINESS UNIT:	*Healthcare*
APPLICATION:	*Dual-Pressure Isolation Rooms*
CONSTRUCTION:	*Modular*
SIZE:	*34,000 SQ. FT.*

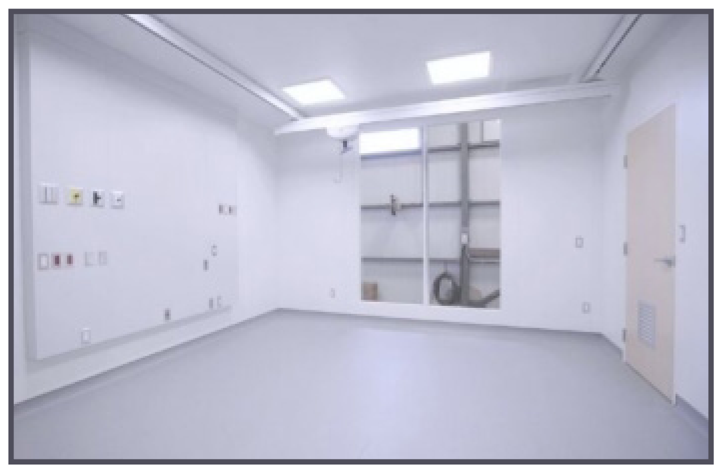


Figure 32 | Rosemont Elevation   Figure 33 | Rosemont Exam Room   Figure 34 | Rosemon Empty Mod

MAISONNEUVE-ROSEMONT EXPANSION

CASE STUDY

SUMMARY

The Rosemont Expansion is a 2.5 billion canadian dollar project, constructed with high-tech modular units with the ability to change pressure, sterilize and isolate each unit. This level of technology in modular construction is incredibly rare. The beauty of it is that systems like these being operated on a commercial scale makes promises of growth. The COVID-19 Pandemic haulted the project until February of 2023. Progress is currently being made as these innovative units begin the manufacturing process.

PURPOSE

The purpose of this case study was to define what is achievable in modular architecture through the advancement of technology. Prior to my precedent studies, the only mention of advanced technology within a modular unit was in pre-fabricated x-ray rooms.

TAKEWAWAYS

The Maisonneuve-Rosemont Expansion is an example of permanent modular construction using the most technologically advanced units. The designers coordinating the expansion noted the significant challenge in increasing treatment capacity due to the odd nature of the existing traditionally constructed hospital.

Figure 35 | Rosemont Nurses Station

Figure 36 | Rosemont Existing Structure

TYPOLOGICAL RESEARCH:

CASE STUDY: SAINT JOSEPH HOSPITAL | DENVER, CO

Figure 37 | St. Joseph Money Shot

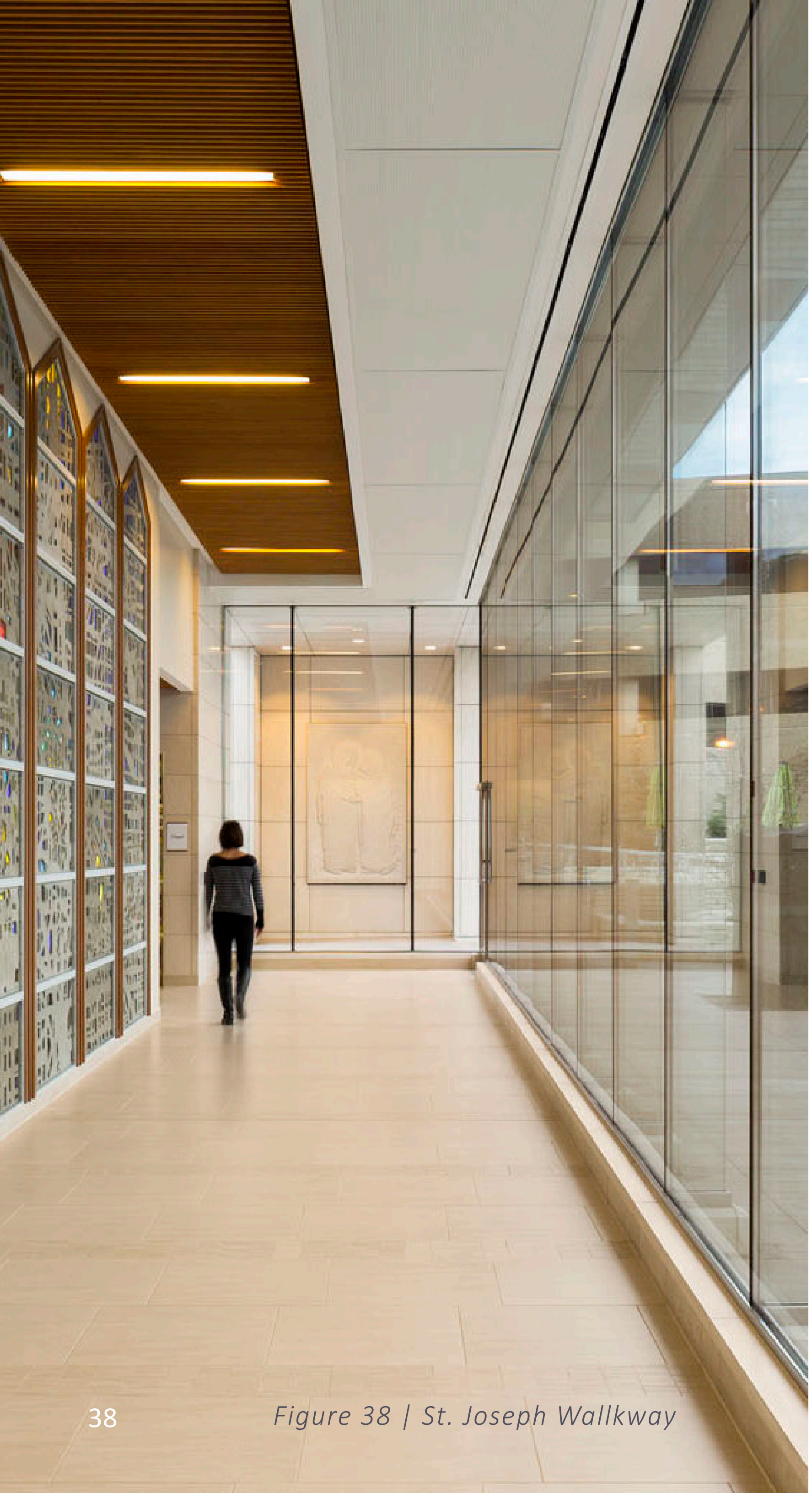


Figure 38 | St. Joseph Wallkway

SAINT JOSEPH HOSPITAL

CASE STUDY

PROJECT DESCRIPTION:

YEAR:	2014
ARCHITECT:	Davis Partnership Architects ZGF Architect LLP H+L Architecture
LOCATION:	Denver, CO
BUSINESS UNIT:	Healthcare, Urban Green Spaces
CONSTRUCTION:	Modular
SIZE:	826,143 SQ. FT.

Figure 39| St. Joseph Lobby

SAINT JOSEPH HOSPITAL

CASE STUDY

SUMMARY

The Saint Joseph Hospital was designed around family care with the project goal to reach the highest level of efficient and safe care as possible. Circulation played a key role in distributing and organizing the spatial layout of the building. This was the most detailed project of all other precedent studies. City ordanance, existing connections, campus requirements and view-plane requirements all influenced the patient circulation path and building envelope. While not an example of modular construction, the attention to detail layed the framework and expectations for my own small scale project.

PURPOSE

This case study was researched with the goal of understanding the project typology in comparison to my own. Waste removal, zoning laws and code compliance only comprise a few of the requirements included in my design solution from this study.

TAKEWAWAYS

Healthcare architecture is one of the most complex architectural typologies. For the first time, the organization of spaces has an influence on the immediate survivability of an occupent. It is imperative that the design solution can conclusively operate with total safety, confidence and efficiency.

Figure 40 | St. Joseph Construction

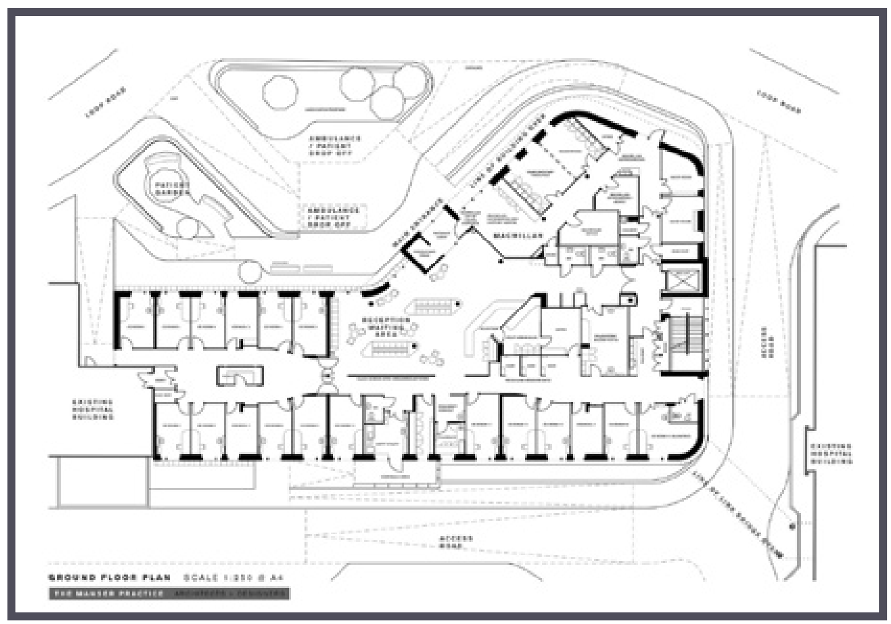
Figure 41 | St. Joseph Entrance

CORRELATIONAL STUDY:
NGS MACMILLAN UNIT | CHESTERFIELD, UK

Figure 43 | NGS Money Shot 2

PROJECT DESCRIPTION:

YEAR:	2017
ARCHITECT:	The Manser Practice
LOCATION:	Calow, UK
BUSINESS UNIT:	Healthcare
PHOTOGRAPHS:	Hufton + Crow
AWARDS:	RIBA East Midlands Building of the Year
CONSTRUCTION:	Traditional (£ 10m)
SIZE:	2,140 SQ. M. 23,034 SQFT.



PROJECT TYPOLOGY

The NGS Macmillan Unit is a standard ambulatory and cancer patient 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 envelope are a great representation of the possibilities provided by traditional construction. Reaching the limits of an organic facade while maintaining high efficiency, it is the perfect sample to be tested.

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 X-rays. These are standardized and universal materials, however, the facade has more creative freedom. This would provide a challenge to create a design solution that not only functions internally but also captures the dynamic aesthetic of the NGS Macmillan's envelope. Utilizing the verticality of the seams between modular units, a similar effect can be drawn from the external fins on the existing facility. Window placement, white façade paneling and elbow shape all embody the characteristics of the form originally designed by The Manser Practice.

Figure 44 | NGS Northwest Entrance

PRELIMINARY RESEARCH

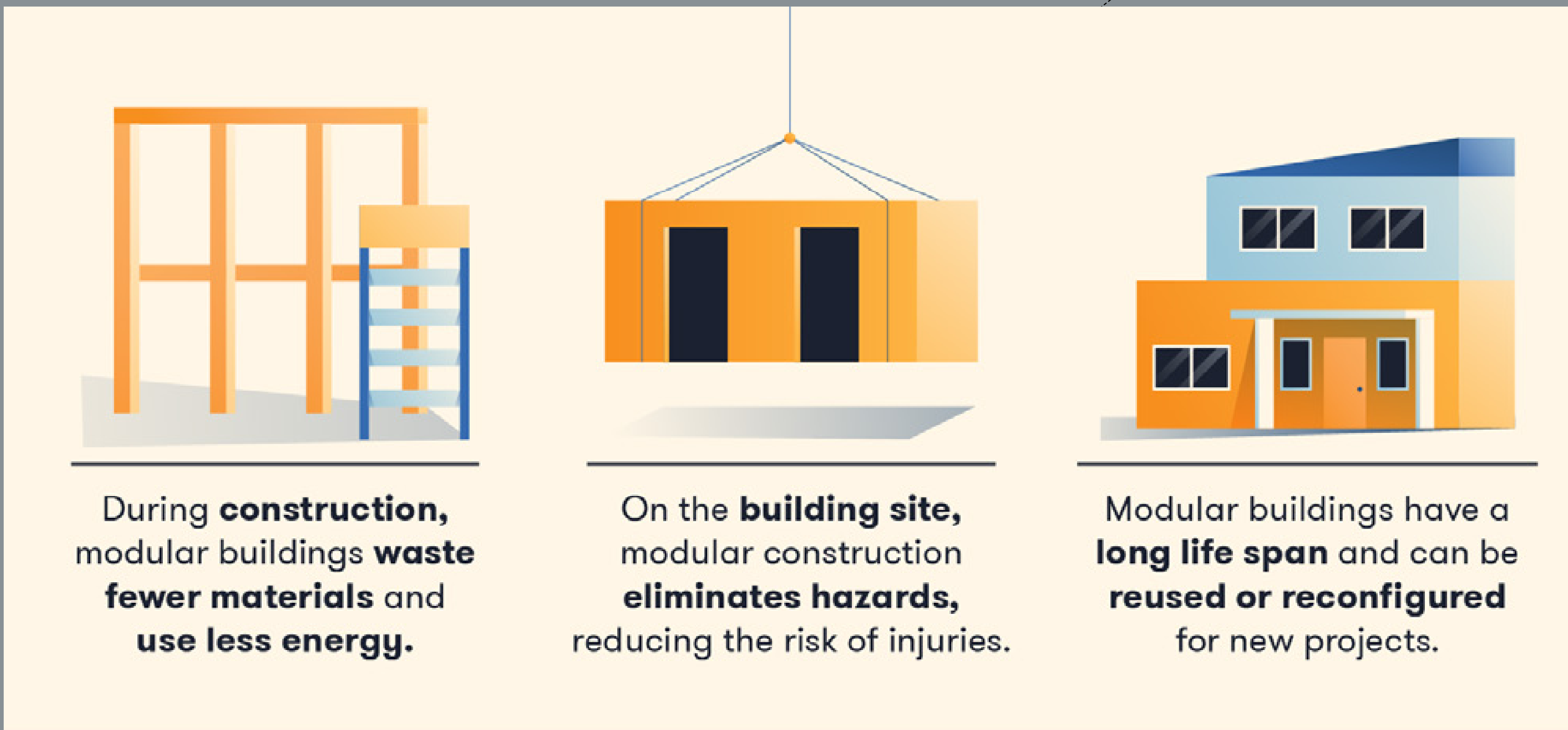


Figure 45 | Modular Benefits Diagram

The maximum Length, Width and Height of a modular unit is defined by its mode of transportation. The two most popular being Semi-Truck and Train Car with train car being a site-specific benefit only applicable if a crane can reach rail to foundation.

The standard maximum limit for an overload semi-truck bed is 13’ x 13’ x 52’. Those parameters are meant to be understood as small scale zoning laws, essentially meaning that curvature and sheared edges cannot surpass the given limits. A modular unit itself is a structural system affixed with aluminum studs, steel columns and beams with the ability to stack up to a maximum of 10 stories with a proper foundation. When these parameters are met, the on-site assembly can reduce the time of construction by nearly 50%.

A MODULAR UNIT ITSELF IS A STRUCTURAL SYSTEM

WITH A CORNER POST SUPPORTED MODULAR UNIT ASSEMBLED WITH A BOLTED MARRIAGE JOINT, 6 TO 10 STOREYS CAN BE ACHIEVED

TRANSPORTATION DRIVES UNIT PARAMETERS

MODULAR ARCHITECTURE HAS THE POTENTIAL FOR A 50% REDUCTION IN MATERIAL WASTE AND TIME-TO-BUILD EFFICIENCY

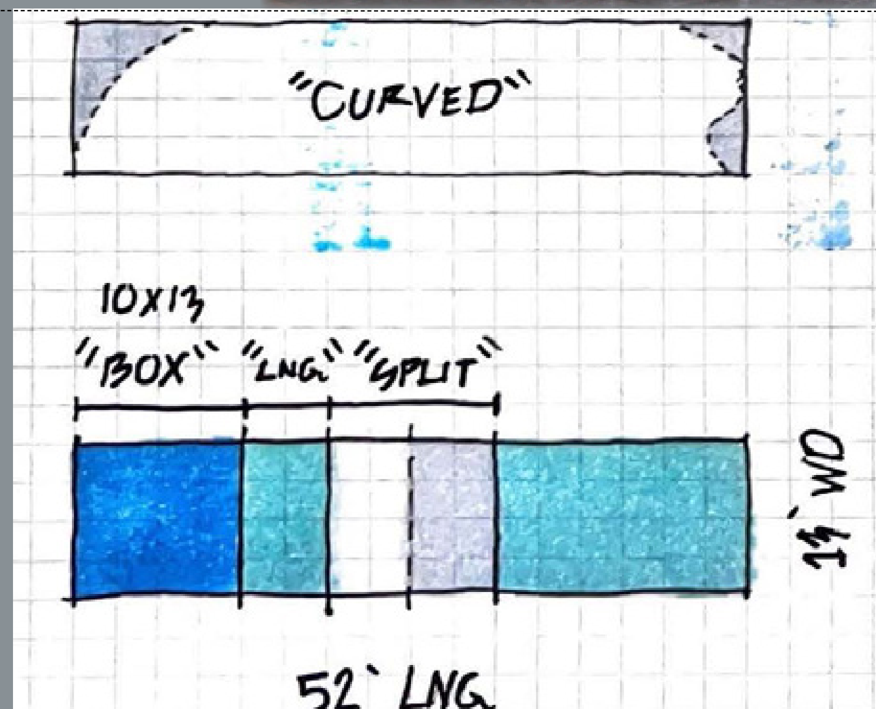


Figure 46 | Complete Modular Unit

Figure 47 | Modular Structture

Figure 48 | Modular Parameters Sketch

CONTEXT

As aforementioned, the chosen site is the NGS Macmillan Unit at the Chesterfield Royal Hospital in Calow, England. Modular design was invented in nearby London making this site a full circle attempt at re-envisioning Modular Architecture.

The Hospital was constructed on the site of Durant Hall, a center for hospice in 1859. Various additions were made throughout the years displaying new healthcare and architectural technology with them. The Hospital had reached a high enough status to catch the eye of King George V who later added “Royal” to its name. When the National Health Service was established in 1948 UK, the now official hospital was central in its part.

The Chesterfield Royal Hospital made its most recent addition in 2017, the NGS Macmillan Unit. Financially supported by the National Garden Scheme and Macmillan Cancer support, the addition would provide ambulatory services, outpa-

Figure 49 | Historic CRH Entrance

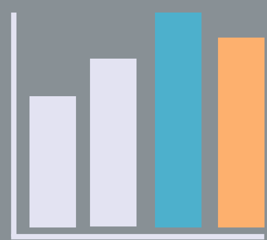
Figure 50 | Historic CRH Treatment

Figure 51 | Historic CRH Emergency Entrance

EF•FI•CA•CY | *noun*

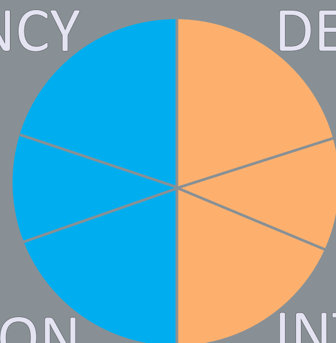
the ability to produce a desired or intended result

The term “efficacy” is defined by the ability to produce a desired or intended result. This can be measured by both Quantitative and Qualitative research. Quantitative being defined by Efficiency, Statistics, Organization and Qualitative being Design, Quality and Intent. The following slides will be marked in the top right-hand corner with one of the two icons based on which research strategy is used.



QUANTITATIVE

QUALITATIVE



EFFICIENCY
STATISTICS
ORGANIZATION
DESIGN
QUALITY
INTENT

ANYLOGIC

SIMULATION START

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, a comparison of the results can be conducted from the existing and theoretical designs, both traditional and modular. The completion of these simulations will address which design solution(s) 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/)

NGS MACMILLAN UNIT - FIRST FLOOR

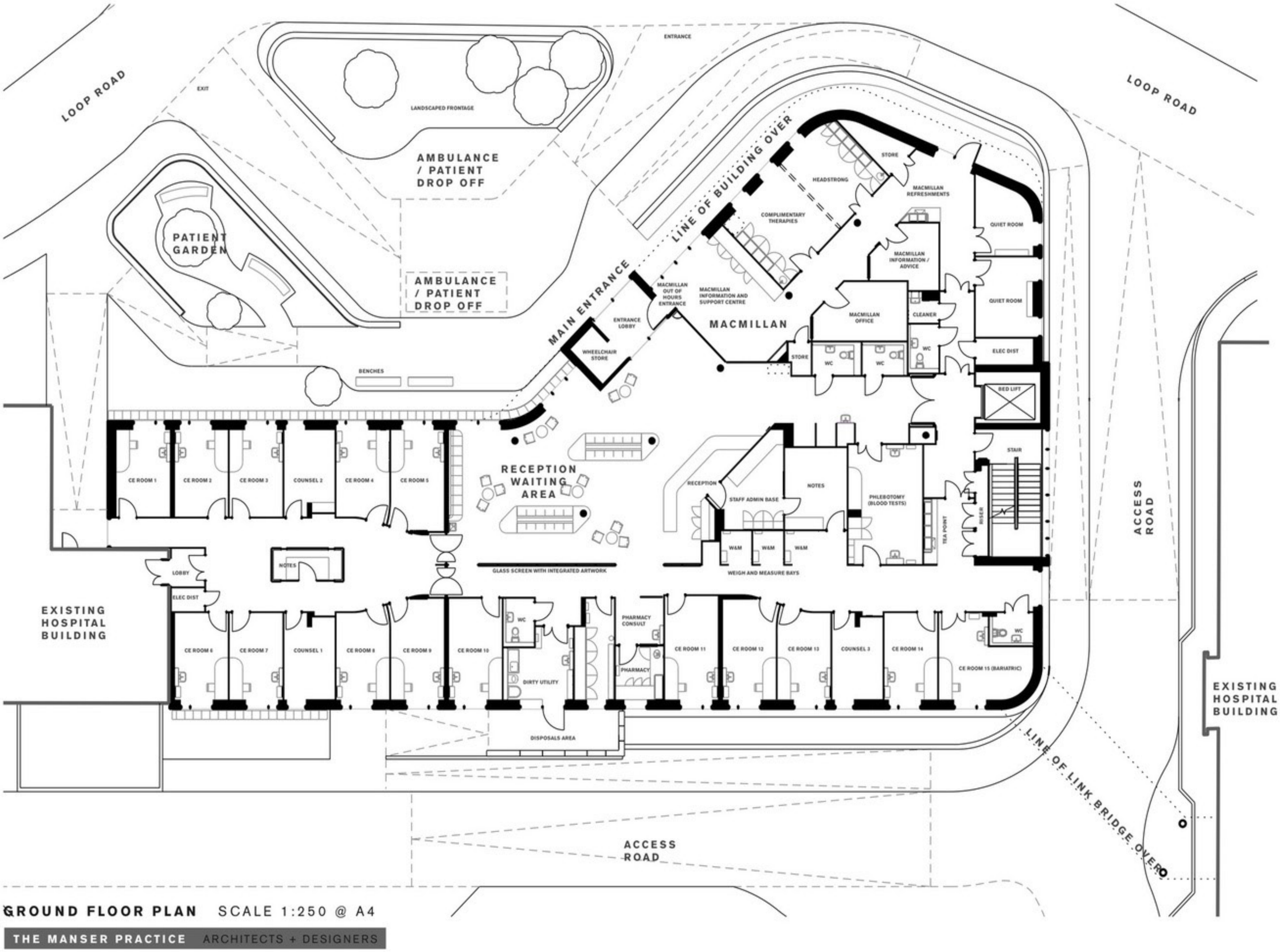


Figure 52 | NGS Macmillan FP1

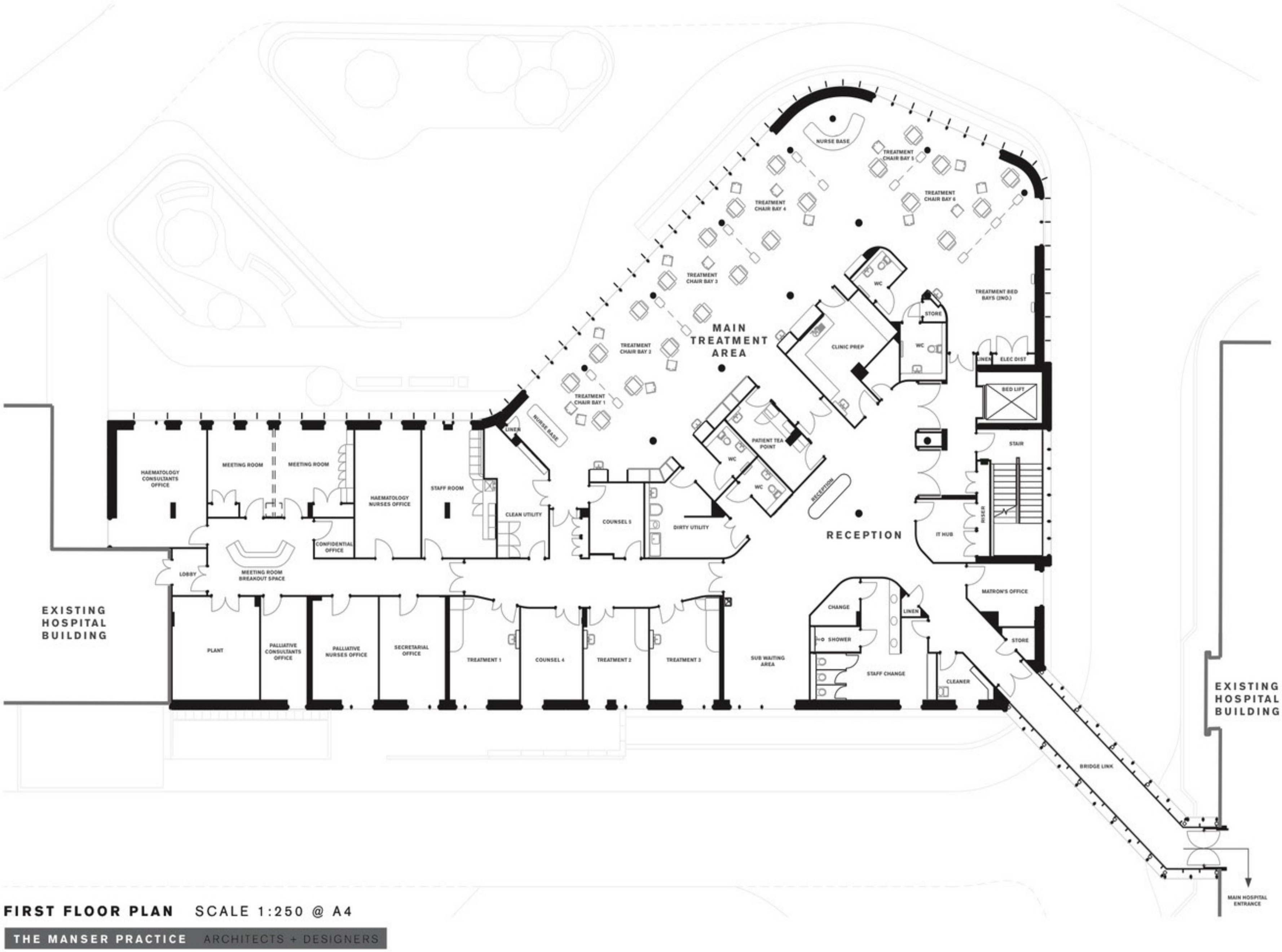
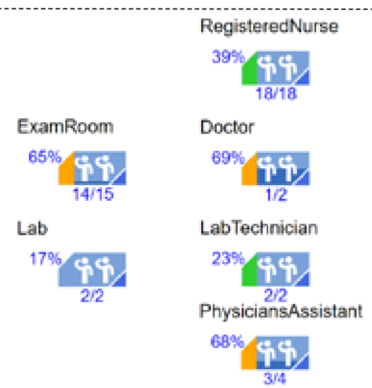


Figure 53 | NGS Macmillan FP2

SPATIAL ORGANIZATION

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

CAPACITY

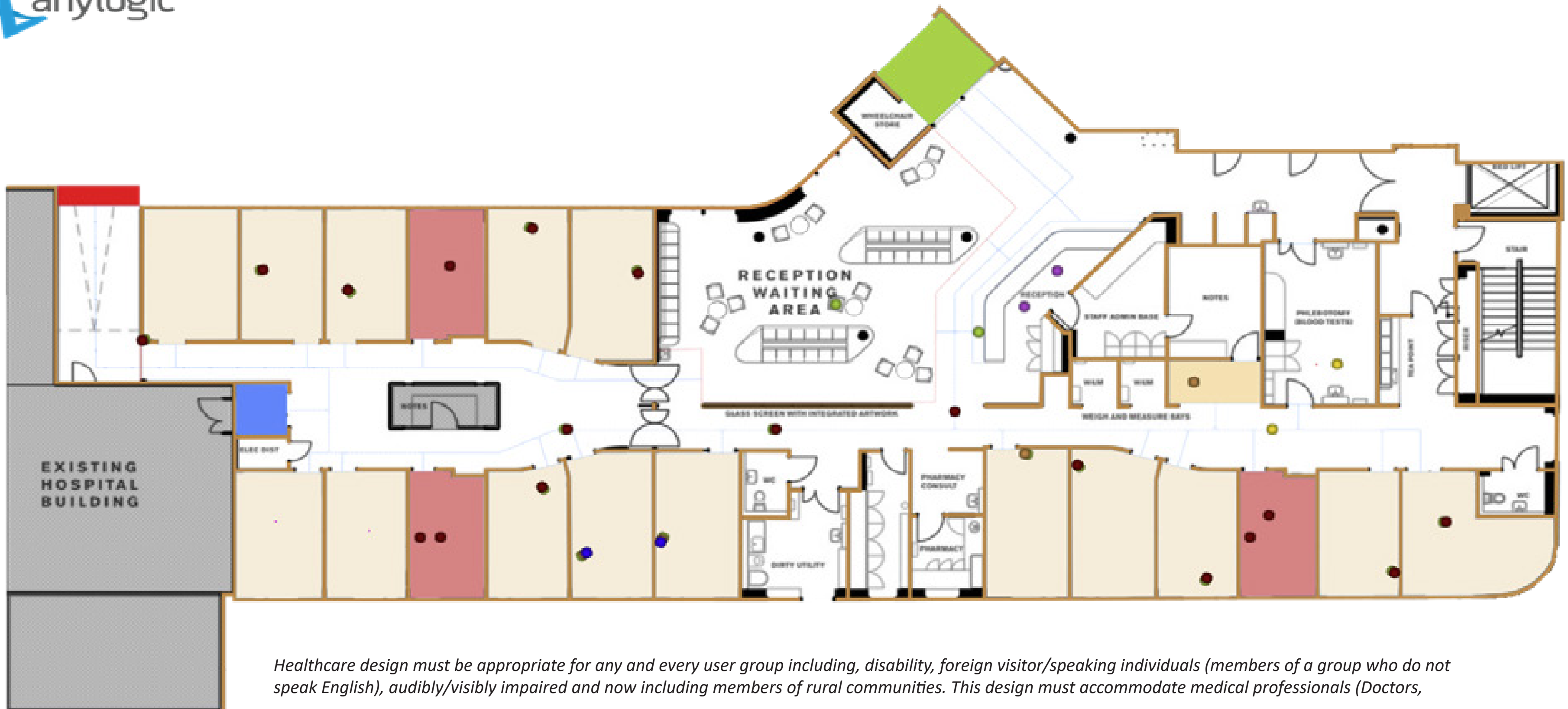


UNDERSTANDING THE "GUI"

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

Figure 54 | NGS Macmillan Anylogic Simulation



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

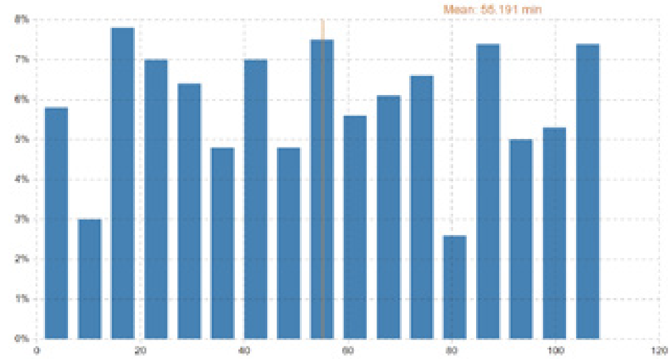
Agents as represented above are the "living" entities within an AnyLogic model. Their appearance and actions can be defined individually or as a population - this is how they fulfill their roles. The listed agents in this model were specifically chosen as the core/ control agents to be used in the replicable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

Figure 55 | Length of Stay Bar Graph



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

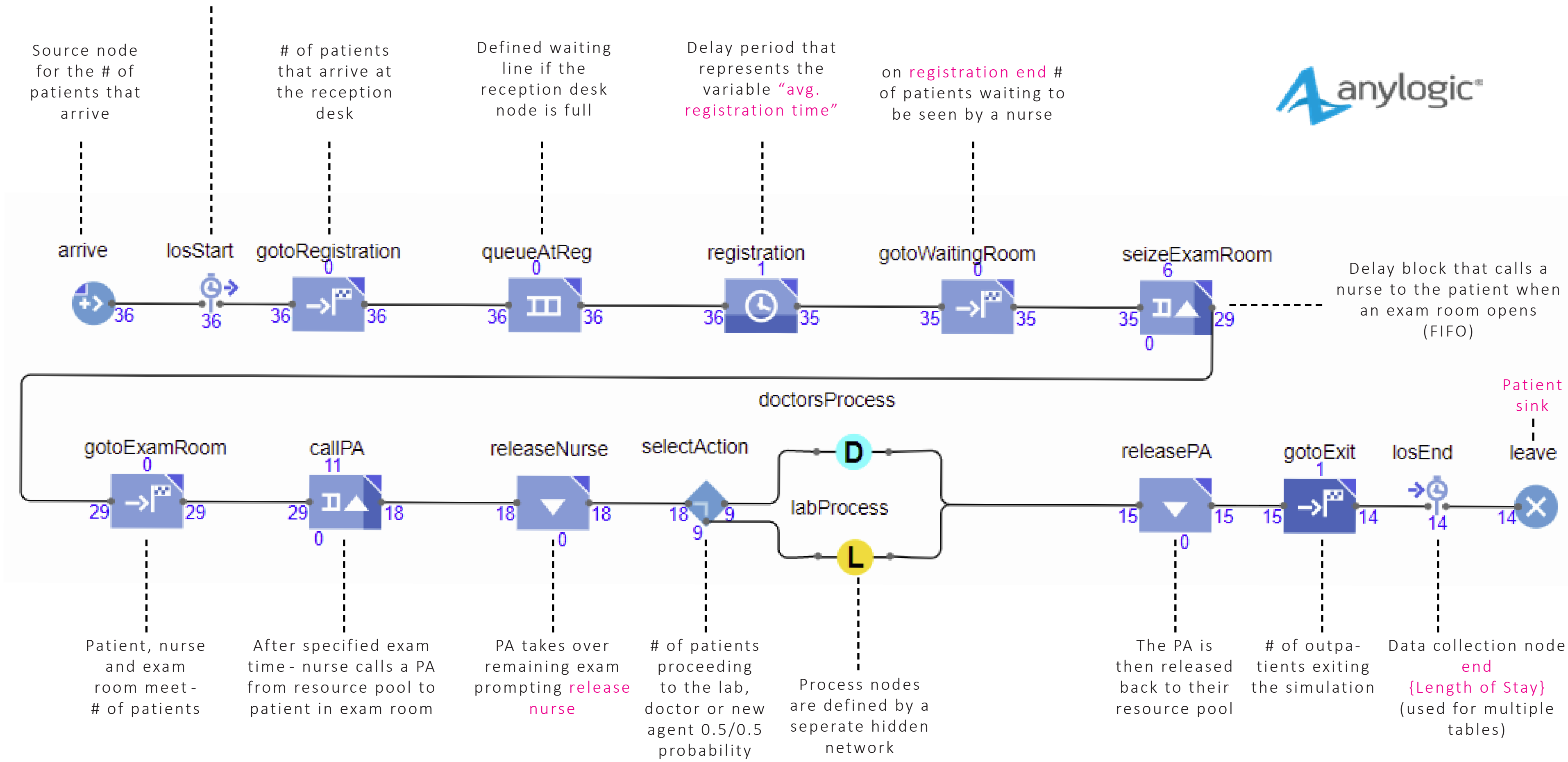


Figure 56 | Anylogic Process Model

DOCTORS PROCESS

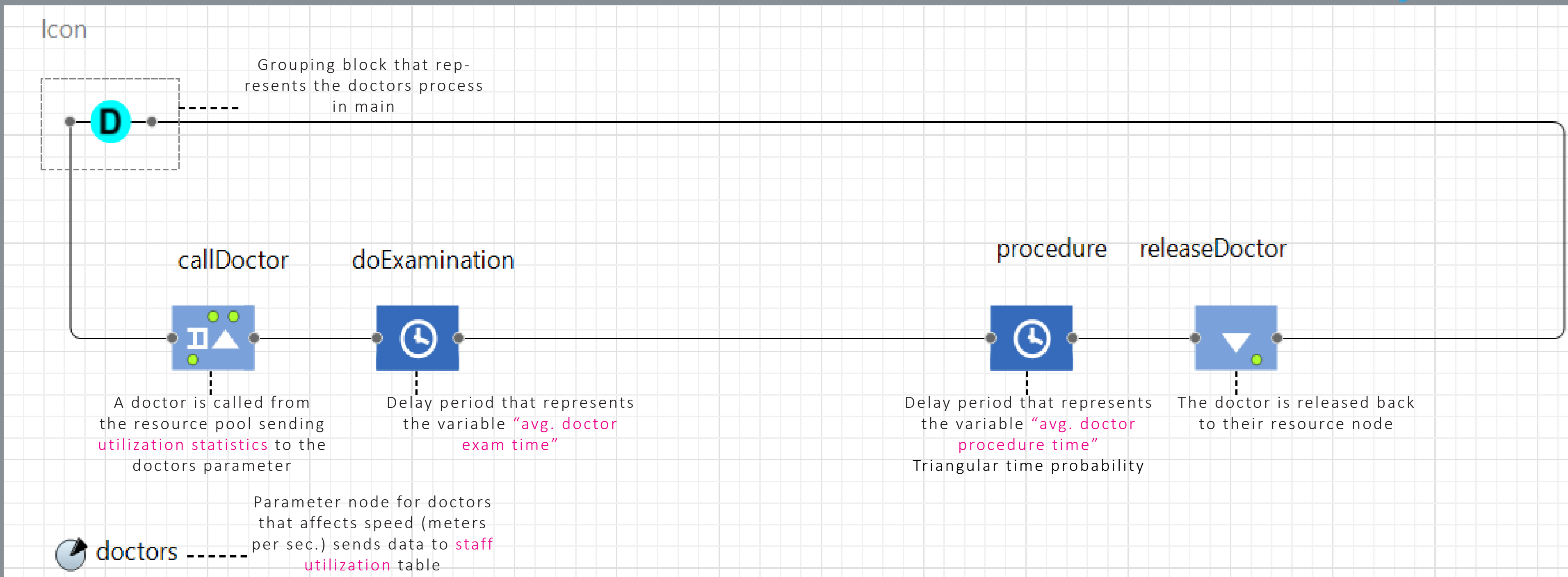


Figure 57 | Anylogic Doctors Process

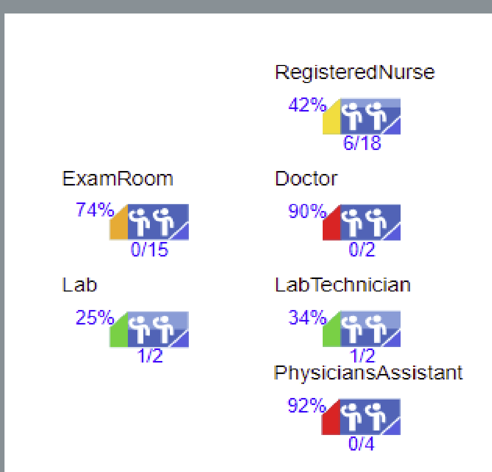


Figure 58 | Anylogic Resource Blocks

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.

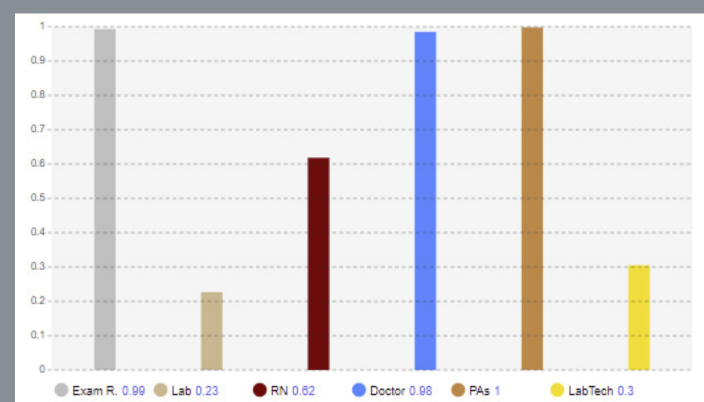
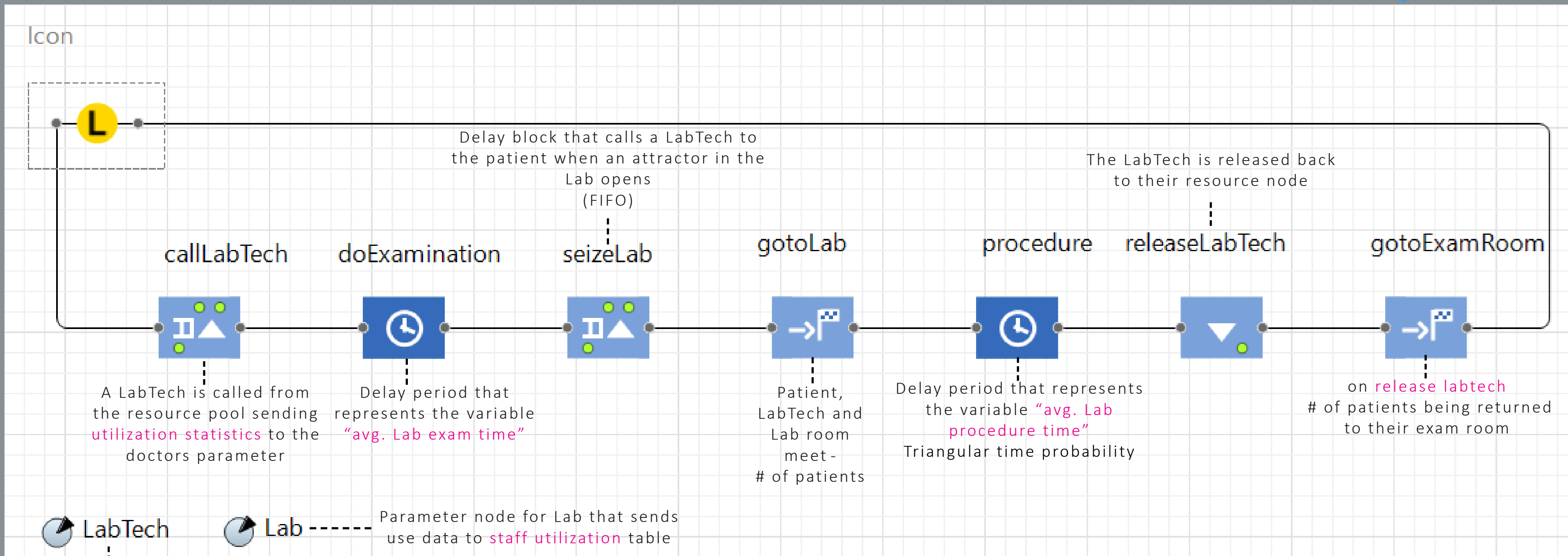


Figure 59 | Anylogic Staff Utilization Bar Graph

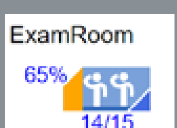
LAB PROCESS

Figure 60 | Anylogic Lab Process



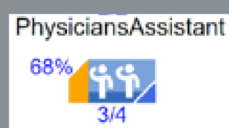
Parameter node for Lab Technicians that affects speed (meters per sec.) sends data to staff utilization table

RESOURCE BLOCKS



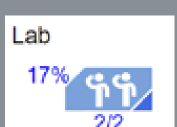
NODES:

callLabTech
gotoExamRoom



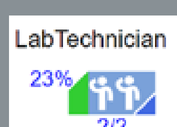
NODES:

doExamination
seizeLab
gotoExamRoom



NODES:

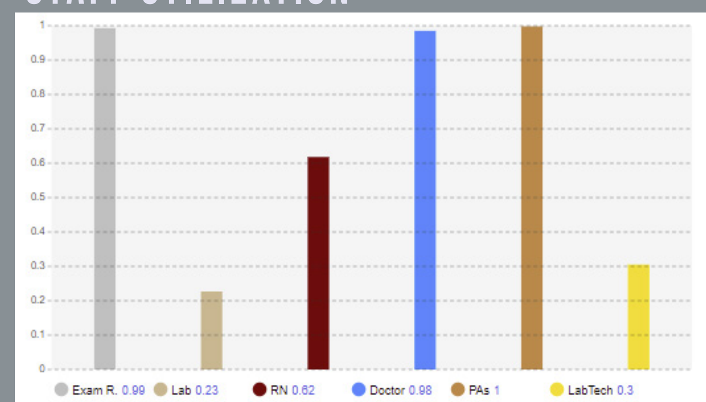
seizeLab
gotoLab
procedure



NODES:

callLabTech
doExamination
seizeLab
gotoLab
procedure
releaseLabTech

STAFF UTILIZATION



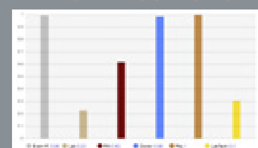
The staff utilization table measures the percent usage of a particular agent. These variables should remain relatively the same across every seperately run simulation. Variables change with arrival rate parameters.

RESULTS

Having completed a fully functional model that measures Pedestrian Flow/Time of Arrival statistics, Length of Stay statistics, 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):

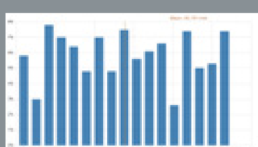


FULL LENGTH ETA (N/S) (6.2 AR):
Distance (m) - 16
ETA (sec.) - 22.4

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

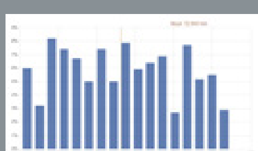
DOCTOR UTILIZATION (6.2 AR):
Patients per hour - 5.55



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 - 5.5



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

Figure 61 | Anylogic Length of Stay Graph 6.5

Figure 62 | Modular Twin Money Shot

PROCESS OF ORGANIZATION

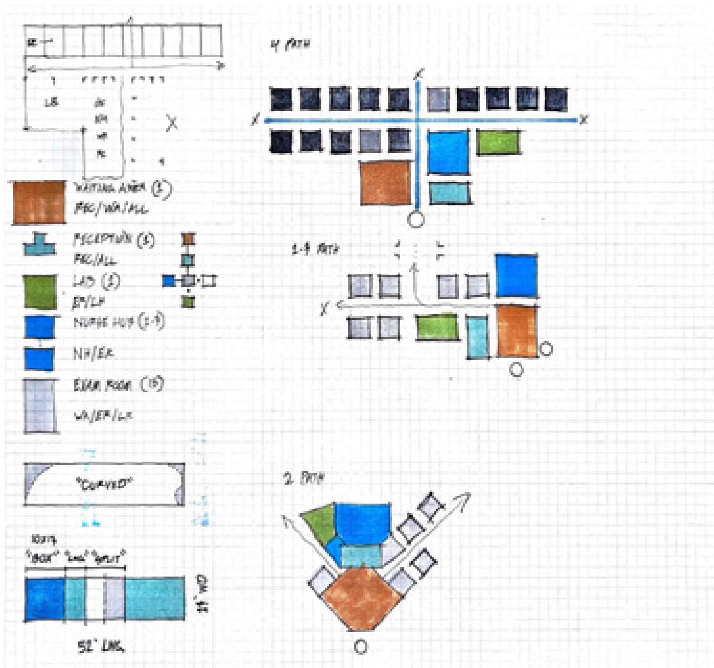


Figure 63 | Process of Organization Sketches

During my initial testing phase of the Anylogic Tree, I imagined a modular structure that was stand alone as opposed to being an addition. In this series of Anylogic samples, the best performing layout was the symmetrical bend in the bottom right corner. This Layout not only benefits from the expandability of modular design but in layout, it can be arrayed in a radial pattern to reach a potential of 400% growth. Through this process I was able to fine tune my logic tree in preparation for my design solution.

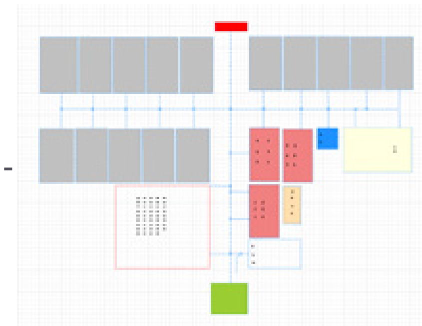


Figure 64 | Spatial Organization 1

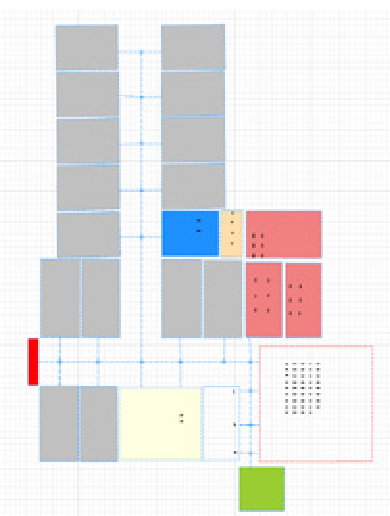


Figure 65 | Spatial Organization 2

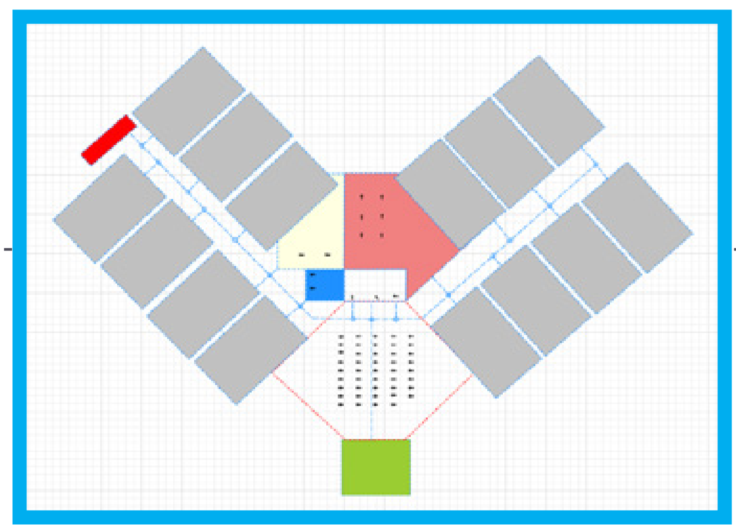


Figure 66 | Spatial Organization 3

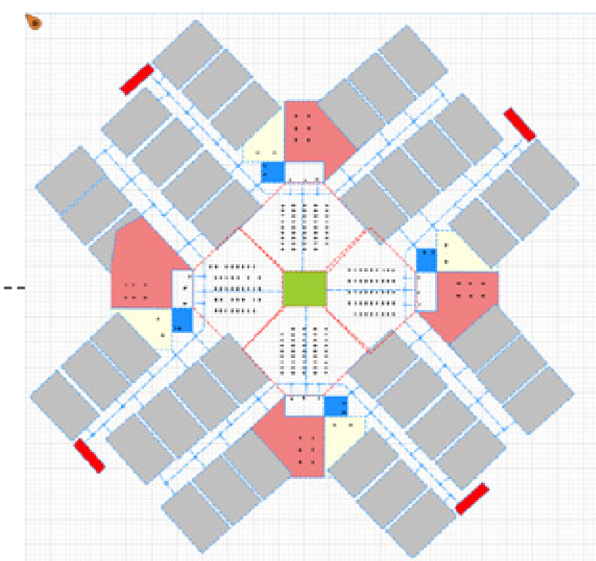
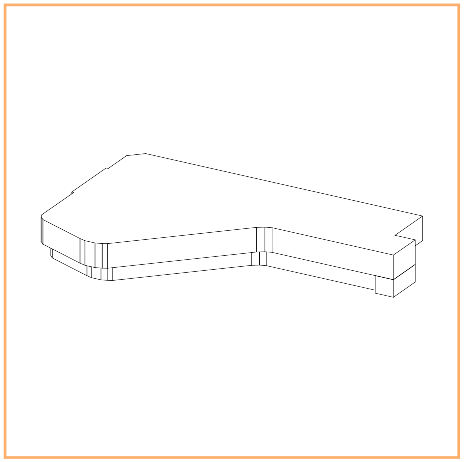


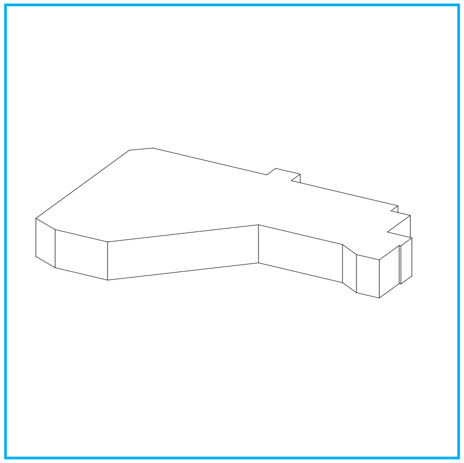
Figure 67 | Spatial Growth

ORGANIZATIONAL MASSING



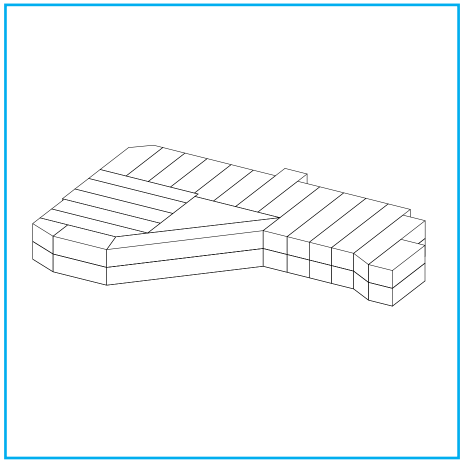
NGS MACMILLAN

Figure 68 | NGS Mass



MODULAR TWIN

Figure 69 | Modular Twin Mass

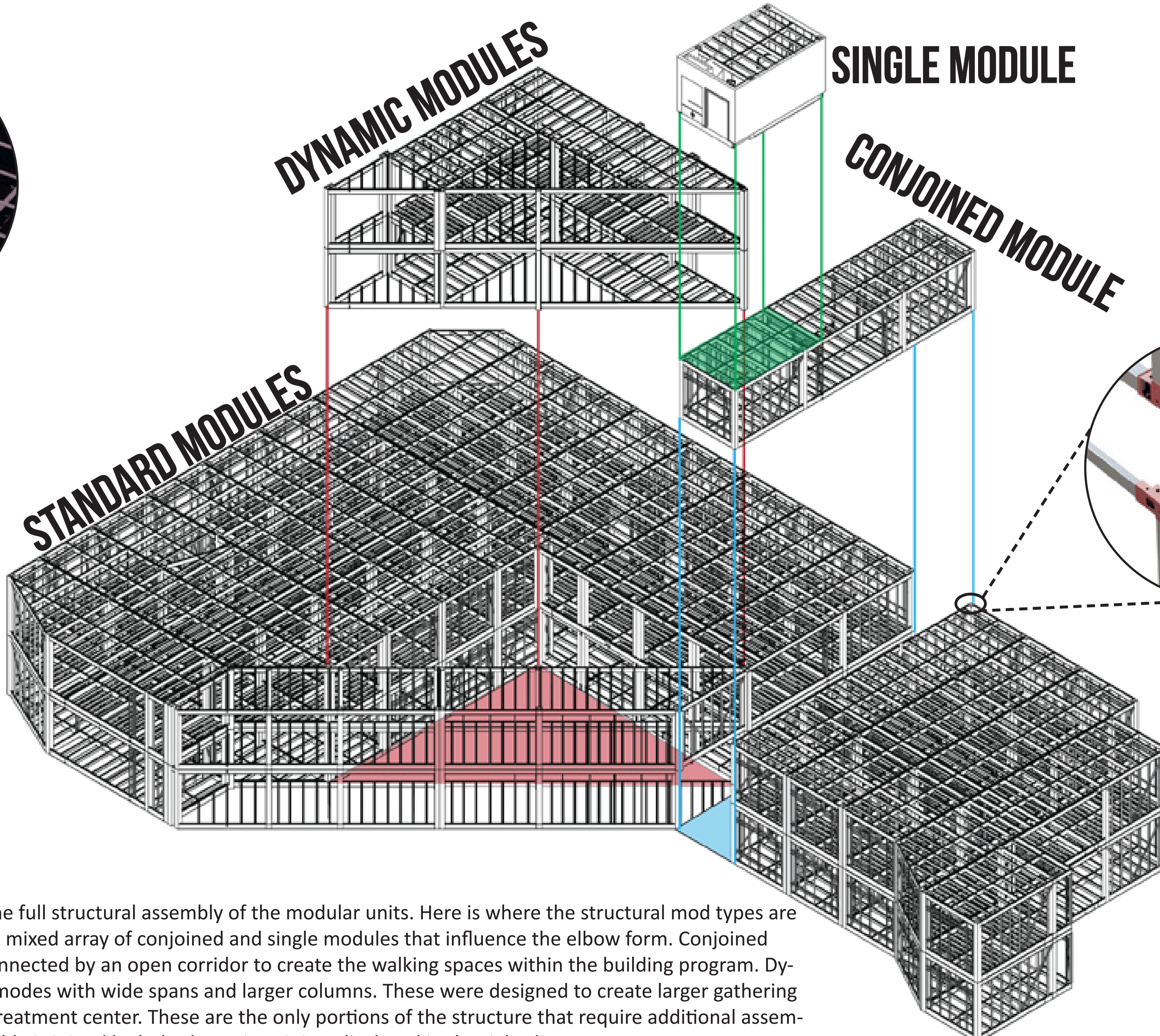


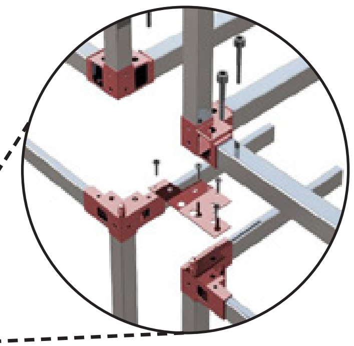
FULL UNIT ASSEMBLY

Figure 70 | Modular Twin Mass Assembly

The Massing of the two units, traditional and modular are identical in form until the individual units of the modular twin emerge from the big picture. Each of these units is a self-sustaining structure containing HVAC, Oxygen Supply and connections to the electrical grid and water lines. This is an important characteristic of modular design that helps prevent the spread of infectious diseases by its inherent isolation.

COMPLETE STRUCTURAL ASSEMBLY





This is an axonometric view of the full structural assembly of the modular units. Here is where the structural mod types are defined. Standard modules are a mixed array of conjoined and single modules that influence the elbow form. Conjoined modules are two single mods connected by an open corridor to create the walking spaces within the building program. Dynamic mods are fully structural modes with wide spans and larger columns. These were designed to create larger gathering spaces such as lobbies and the treatment center. These are the only portions of the structure that require additional assembly on-site. The complete ensemble is joined by bolted marriage joints displayed in the right diagram.

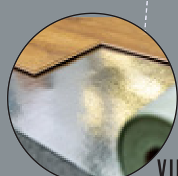
Figure 71 | Complete Structural Assembly

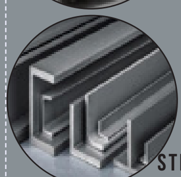
Figure 72 | Bolted Marriage Joints

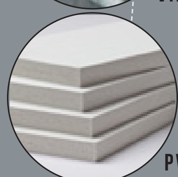
INDIVIDUAL UNIT ASSEMBLY

The individual unit design focuses on cleanliness and structural integrity. Standard structural materials such as aluminum and steel are applied to the bones of the unit. Sealed Vinyl flooring is a strong and lightweight material that is non-porous which prevents moisture damage and makes for easy sterilization. Likewise, Polyvinyl Chloride Wall tiles line the interior of the unit for its similar properties. HPL or (High Pressure Laminate Tiles) are applied to the exterior faces of the mods which have chemical resistance, wear resistance and most importantly, fire resistance since the crevasse housing the compressed oxygen exists just within its envelope.


ALUMINUM


VINYL


STEEL


PVC

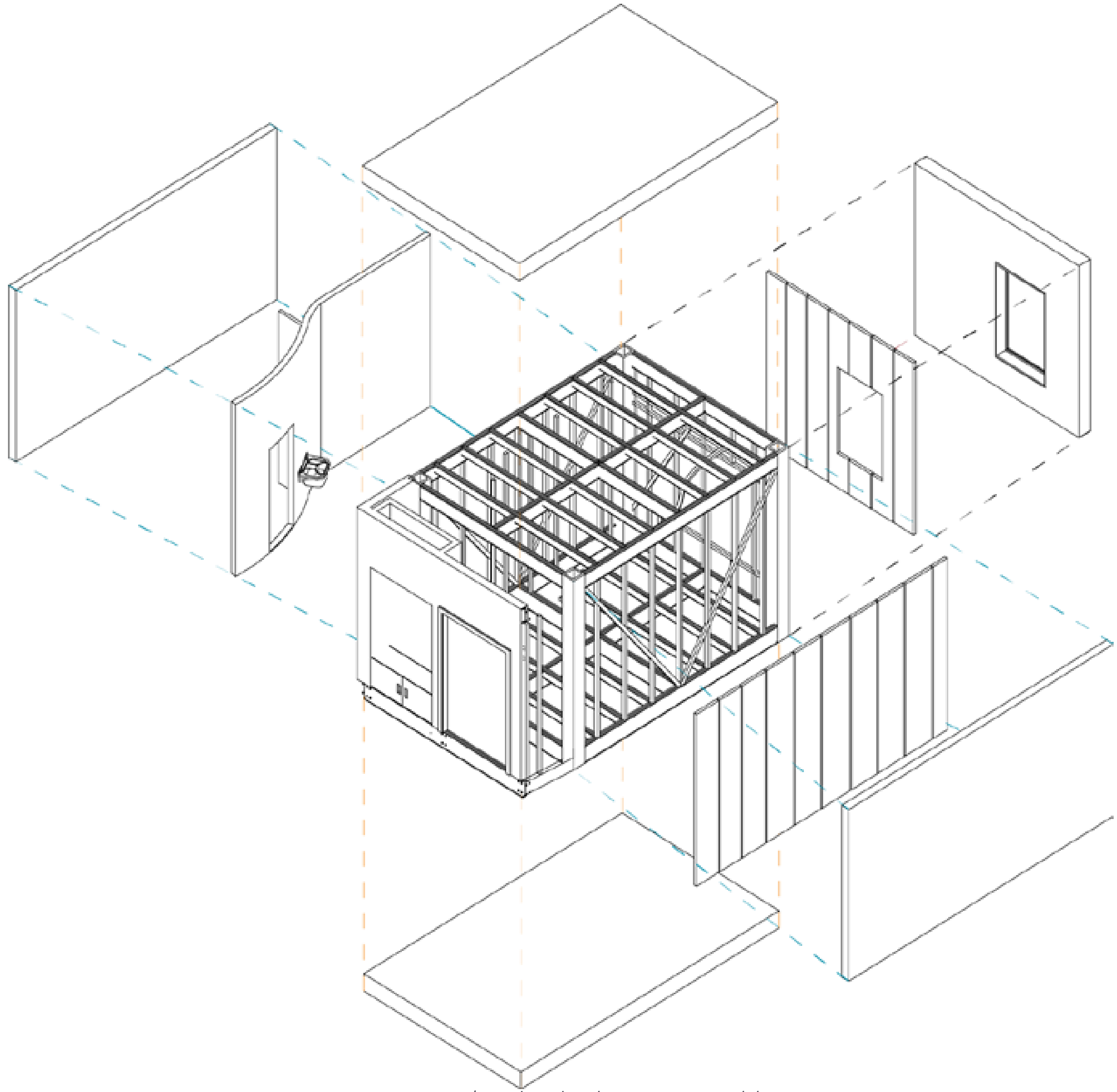


Figure 73 | Individual Unit Assembly

Figure 74 | Physical Model Scale

This is my 1:18 scale model of the unit constructed with basswood and acrylic. The roof and one of the wall panels are transparent to display the structural components of the mods and provide a better view of the interior form. Curvature is the primary design element psychologically immobilizing patients, allowing rest and a soft environment.

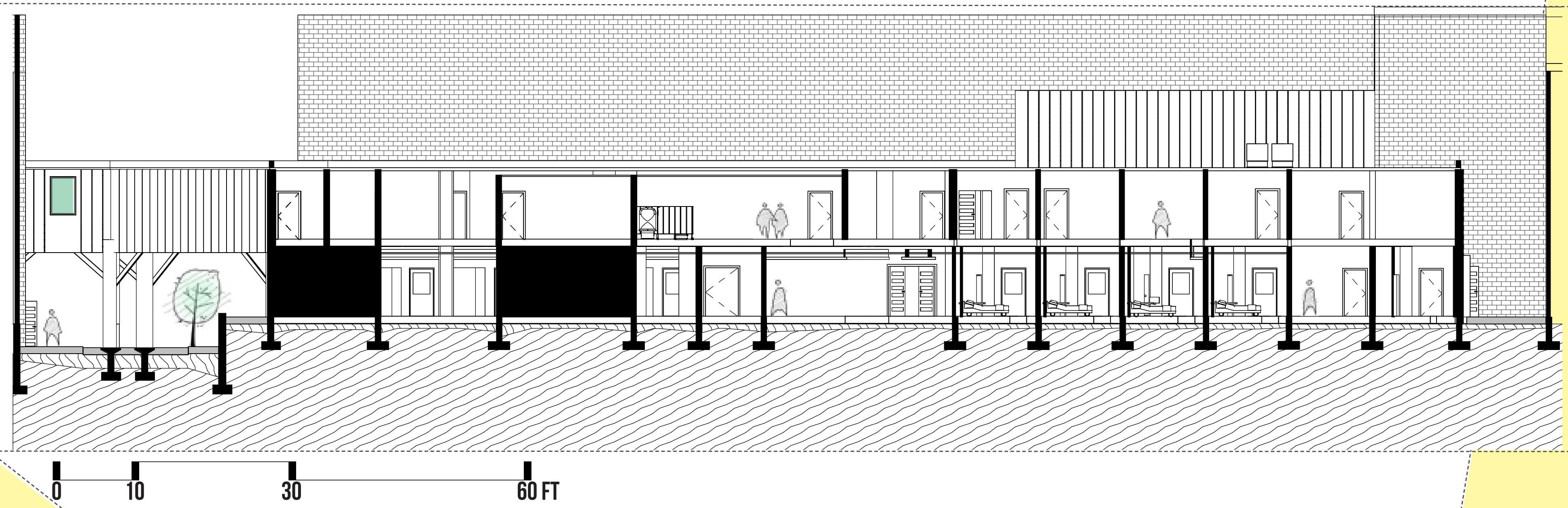
Figure 75 | Physical Model Hallway Entrance

These elements are represented in the drop ceiling which houses a diffused LED light strip which bends with the form as well as the intake for the HVAC system. The curved separation wall serves a functional purpose, housing a walk-in storage room, water access to the sink, panel access to the electrical box and compartment housing the oxygen storage.

Figure 76 | Physical Model Exterior WIndow

Figure 77 | Physical Model Overhead

SECTION CUT

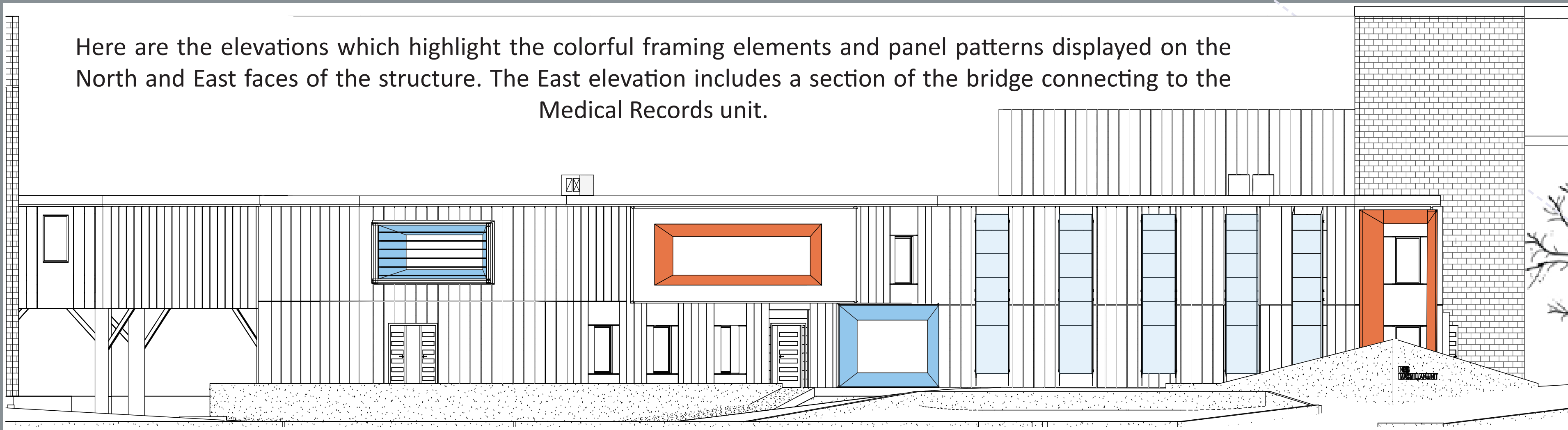


This is a section cut of the Modular Twin which shows the structural components now encased in architectural wall elements. This showcases spatial interaction, change in grade and footings beneath the English frost line.

Figure 78 | Modular Twin Section Cut

ELEVATIONS

Here are the elevations which highlight the colorful framing elements and panel patterns displayed on the North and East faces of the structure. The East elevation includes a section of the bridge connecting to the Medical Records unit.



NORTH

Figure 79 | Modular Twin N Elevation

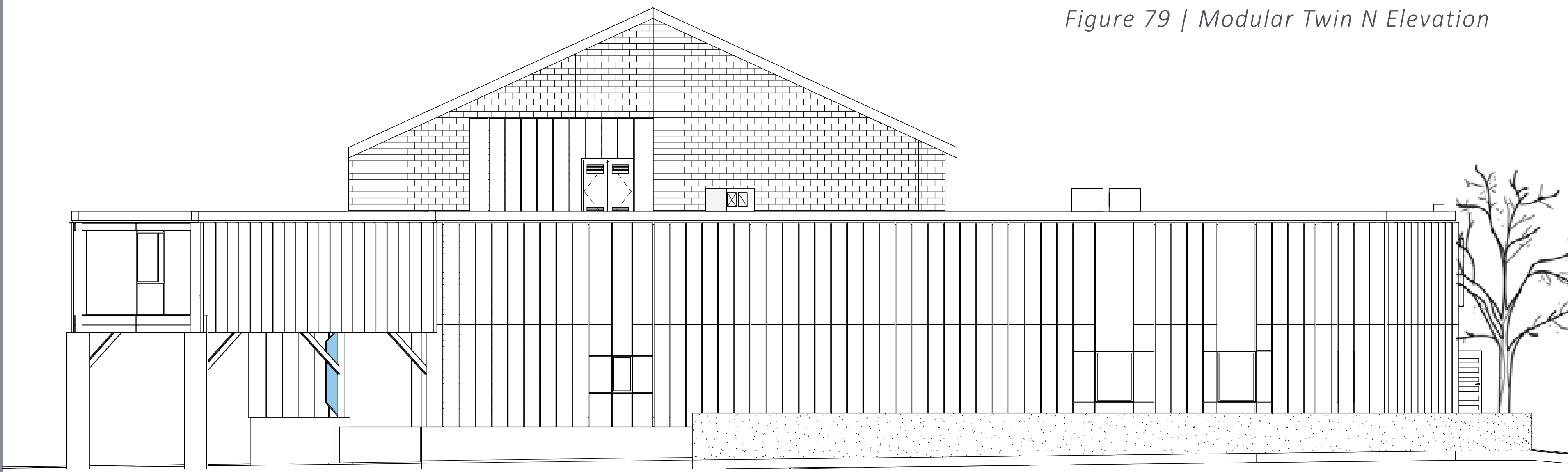
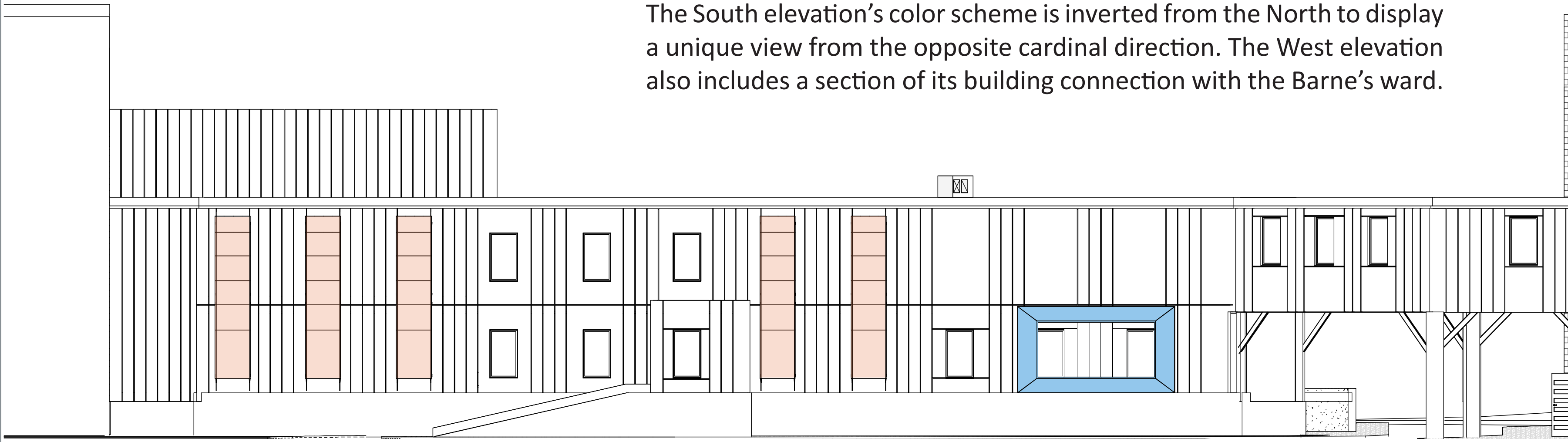


Figure 80 | Modular Twin E Elevation

EAST

The South elevation's color scheme is inverted from the North to display a unique view from the opposite cardinal direction. The West elevation also includes a section of its building connection with the Barne's ward.



SOUTH

Figure 81 | Modular Twin S Elevation

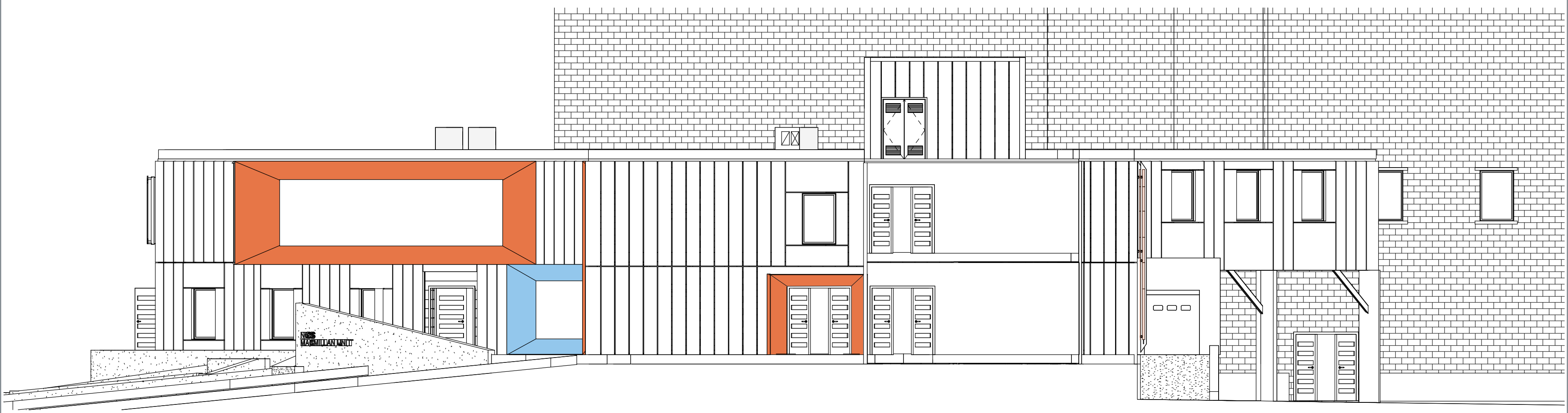


Figure 82 | Modular Twin W Elevation

WEST

COMPLETED CONSTRUCTION

Figure 83 | Modular Twin NW Entrance

Figure 84 | Modular Twin Bridge

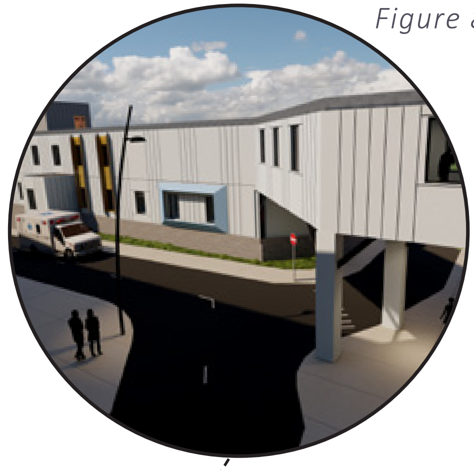


Figure 85 | Modular Twin Patient Garden

Now in complete composition, design elements and site context is visualized from the Northwest entrance, the second floor bridge connection and Patient Garden.

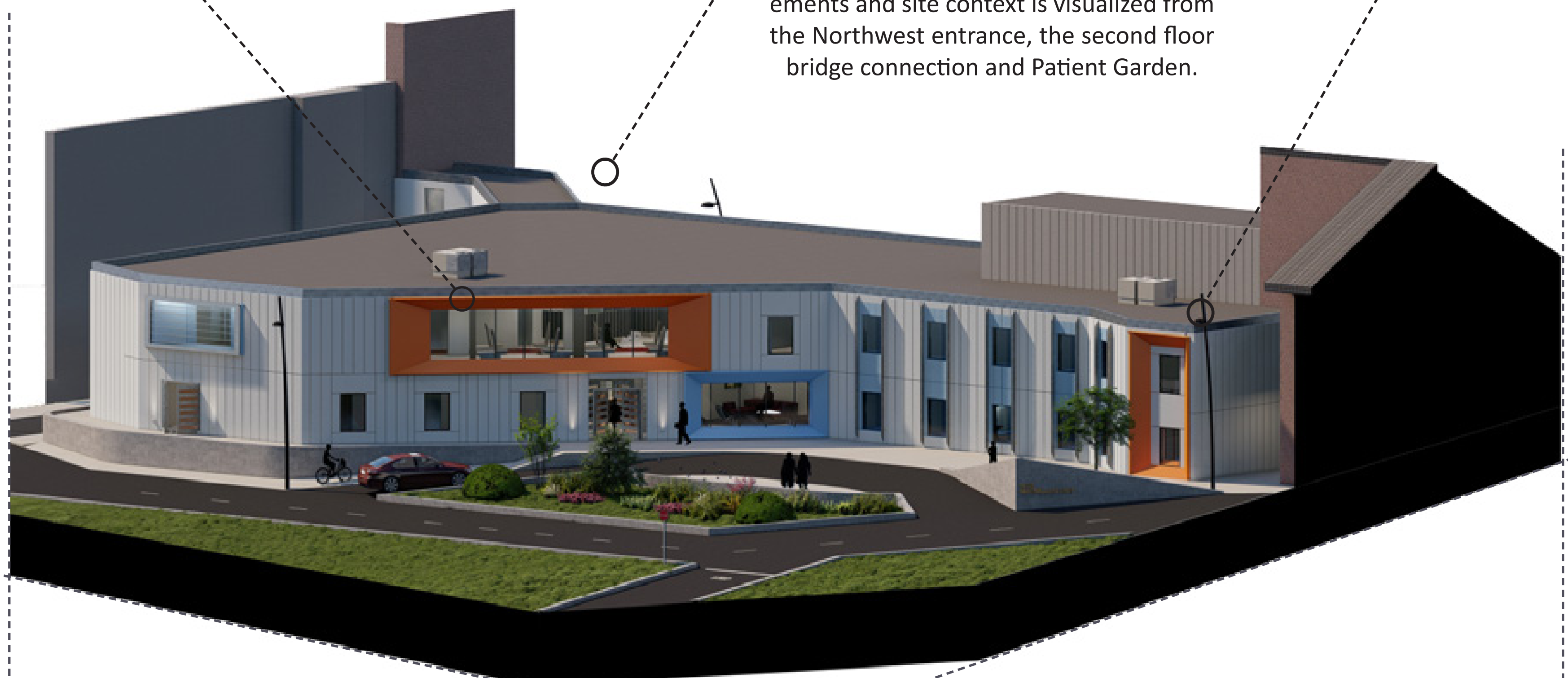


Figure 86 | Modular Twin Axonometric

DESIGN ELEMENTS

NORTHWEST - MAIN ENTRANCE

The Modular Twin's design philosophy takes subtle influence from its traditional counterpart, further solidifying the theoretical instance where it could be designed by The Manser Practice.

COLOR THEORY

- Pureness, Cleanliness, Productivity, Trust
- Positivity, Creativity, Energy, Happiness
- Confidence, Passion, Warmth, Power

My interpretation of a cancer treatment clinic is that it should feel happy, youthful, positive and exciting and what better way than with color. Color theory is a psychological study of how humans are subconsciously affected by the hues and saturation of color. The three I have chosen are blue, orange and red. Blue is associated with Pureness, Cleanliness and trust and is the most popular color in the field of healthcare due to its influence on productivity. Orange is associated with positivity, creativity and happiness and is well known for its affect on energy and growth. Lastly, the color red is associated with passion, warmth and power and is located on the interior spaces where patients and staff interact the most because of its qualities of trust and confidence.

Figure 87| NGS Macmillan NW Entrance

NORTHWEST - MAIN ENTRANCE

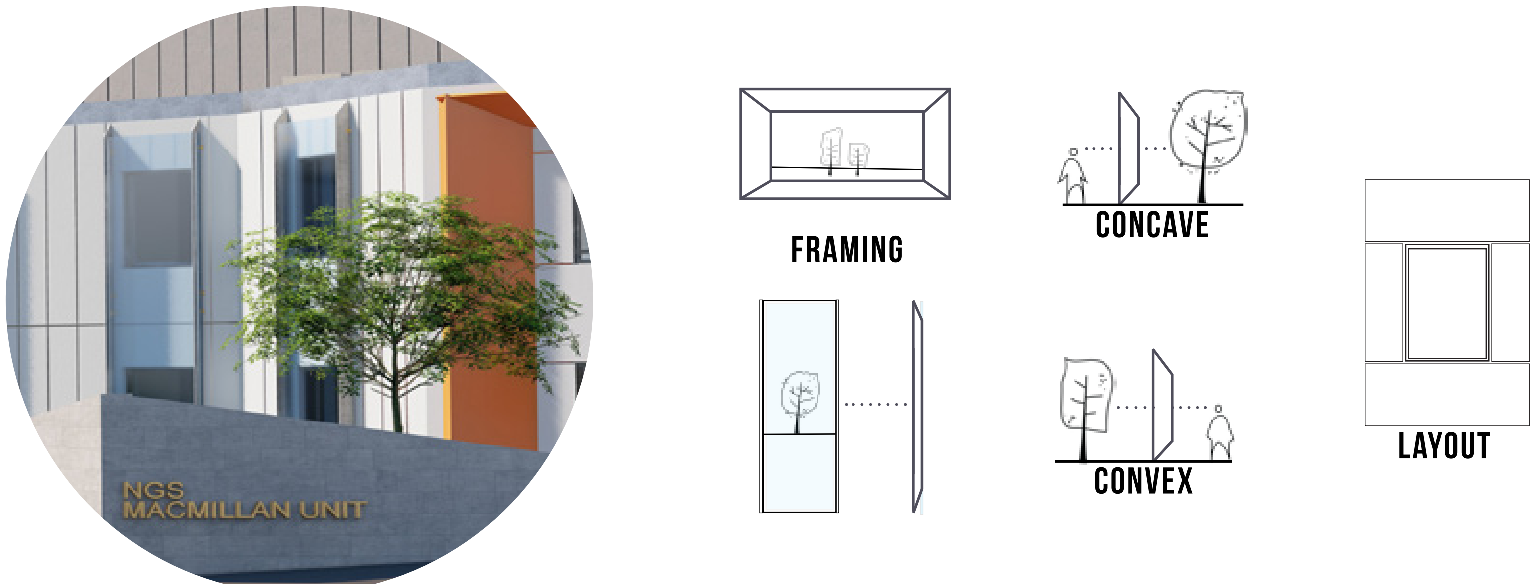


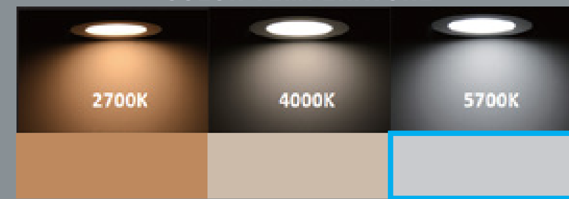
Figure 88 | Modular Twin Design Elements

Fixed to the vertical fins are fully transparent, colorful polycarbonate panels. The separation of the panels with the windows was intentional as the colorful shadow bends with the suns rays throughout the day, giving the façade a different appearance each day. The concave and convex framing elements tighten the lens looking in and allow the colorful fins flare out. This paints the otherwise white face of the building with more excitement. On the other hand, the views looking out are otherwise unobstructed due to the shape of the framing rim.

The pattern of the white panels are also significant, dividing the structure into a noticeable cut slice on the horizontal axis but blended and uniform vertically. At window openings without extruding framing elements, the panels shape mock lintels, echoing the appearance of the real lintels on the surrounding architecture.

Figure 89 | Interior - Primary Corridor

COLOR TEMPERATURE



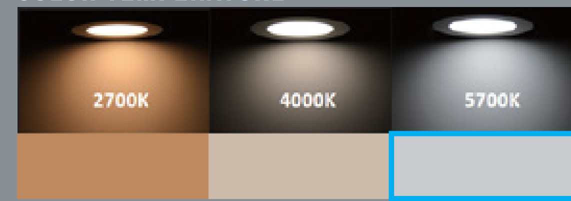
The primary corridor on the first floor is the busiest hallway in the entire building. This linear space is created using conjoined modular units, otherwise meaning exam rooms line both of its sides. Each exam room includes an alcove in the corridor so that guests and visitors of the patient are not forced to return to the lobby in the event they must leave the room. These light blue nooks feature undercarriage storage and an overhead reading light. The bench inside is cushioned in case of the event that users experience a prolonged stay.

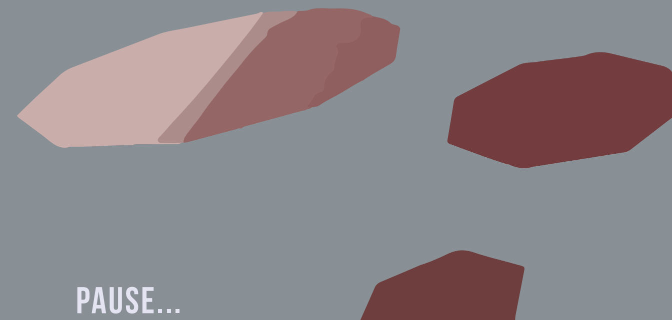
Color theory is apparent once more, this time with the addition of light temperature. Every space that is occupied by medical professionals is lit by 5700 Kelvin and above light fixtures because of its cooling effect and psychological impact on productivity. Directional elements influence circulation and efficiency, in this case the laminate floor is two toned with a central strip of red accompanied by parallel led strips on the ceiling creating the visual affect I have coined the "highway".

Figure 90 | Interior - Standard Exam Room

INTERIOR - STANDARD EXAM ROOM

COLOR TEMPERATURE





PAUSE...

Each unit is also lit by the same cool temperature to maintain focus among the medical staff. A built-in seat is nestled in the corner opposite the patients bed. This was to avoid the awkward relocation of foldable chairs each time the doctor or nurse switches bed sides. The pattern displayed in these units are called pause as they show the deconstruction of the highway pattern signifying a finish line and a place for pause.

COLOR THEORY

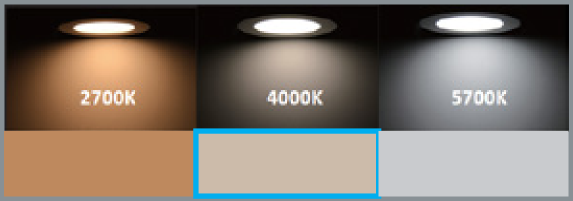
Figure 91 | Interior - Main Lobby

The first floor Lobby is saturated in warm lighting, intended to soften the transition patients experience from the outdoors – in. The curved shape of the floor tiles in rhythm with the ceiling lights slows occupants in their travels. The anticipation patients feel in a hospital lobby can be overwhelming so it was important to design a space that would help them relax. In the lower right-hand corner is an image of the current NGS Macmillan lobby, featuring bright LED's and exposing floor to ceiling windows.

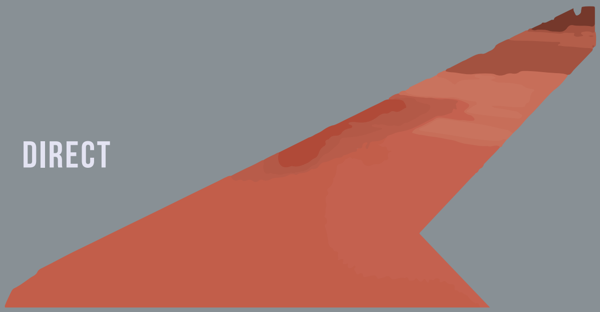
Figure 92 | NGS Main Lobby

Figure 93 | Interior - Treatment Center

COLOR TEMPERATURE



DIRECT



Lastly, the Treatment center, the primary space for efficient outpatient treatment and dialysis, joins the duality of spaces, efficient and relaxing. Warm hues paint the floor while the red line directs staff down an unobstructed hallway between the nursing station and other important tertiary spaces necessary for patient treatment.

COLOR THEORY

SITE PLAN

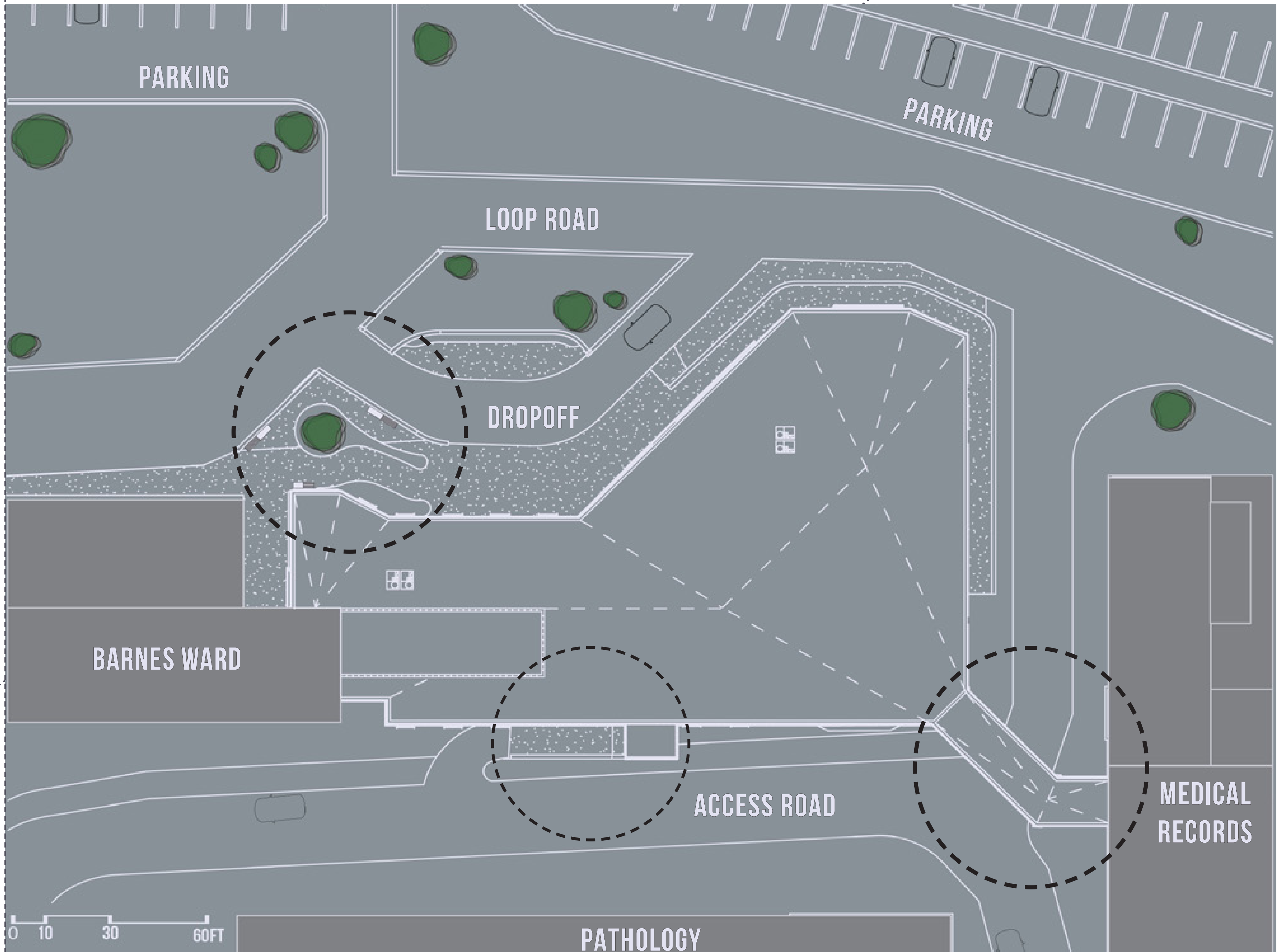
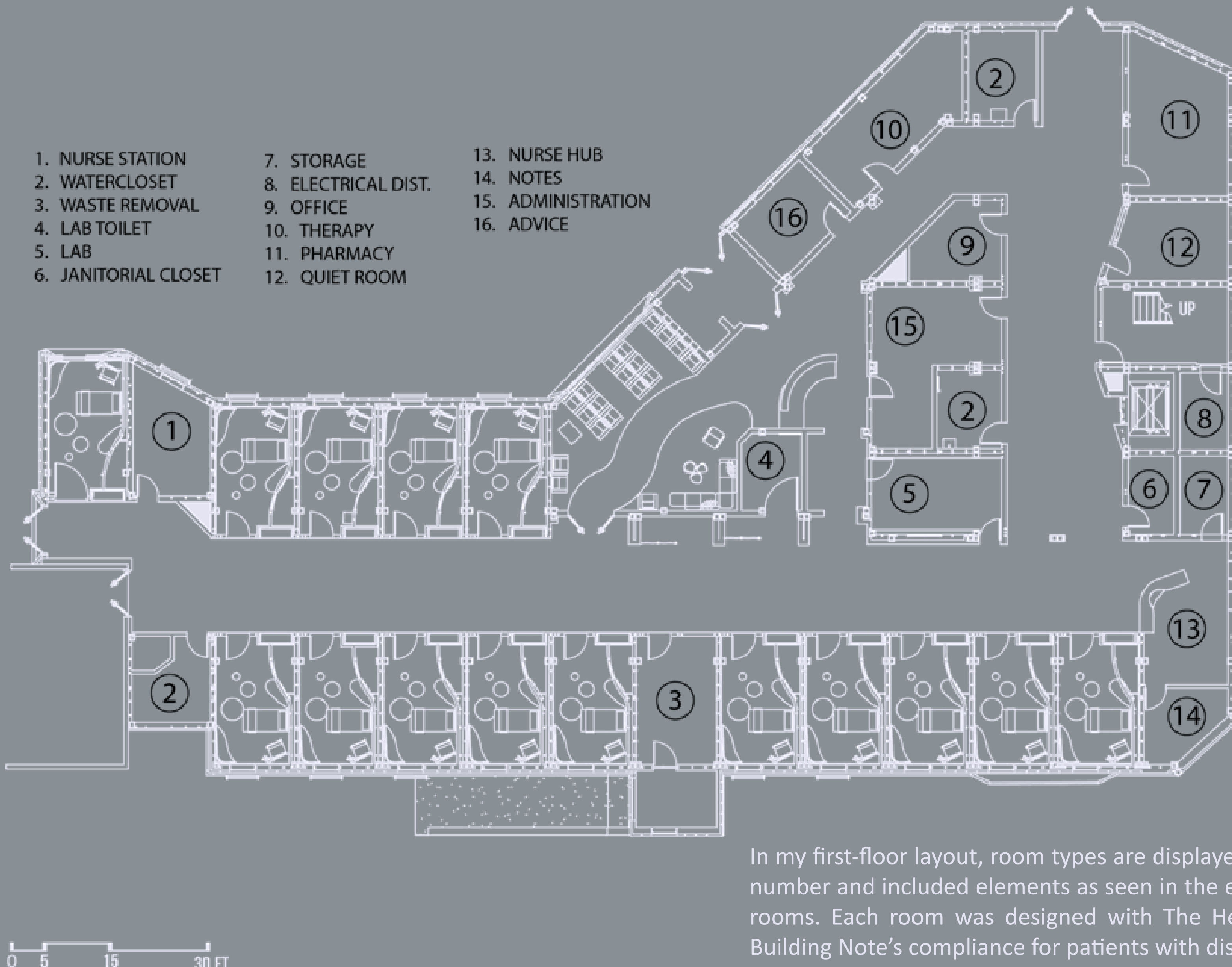


Figure 94 | Site Plan

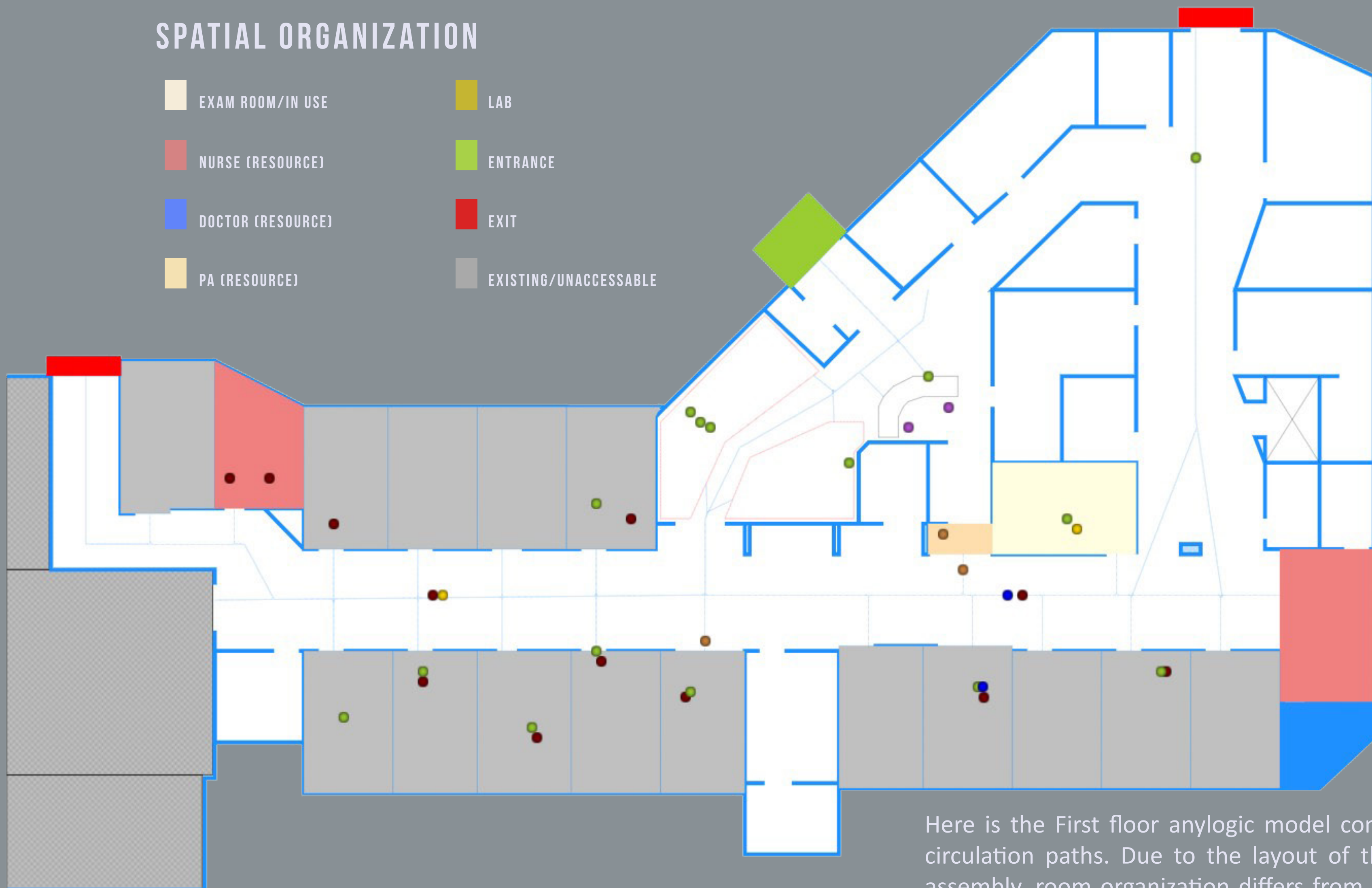
FIRST FLOOR PLAN



In my first-floor layout, room types are displayed by number and included elements as seen in the exam rooms. Each room was designed with The Health Building Note's compliance for patients with disabilities and general healthcare guidance.

Figure 95 | First Floor Plan

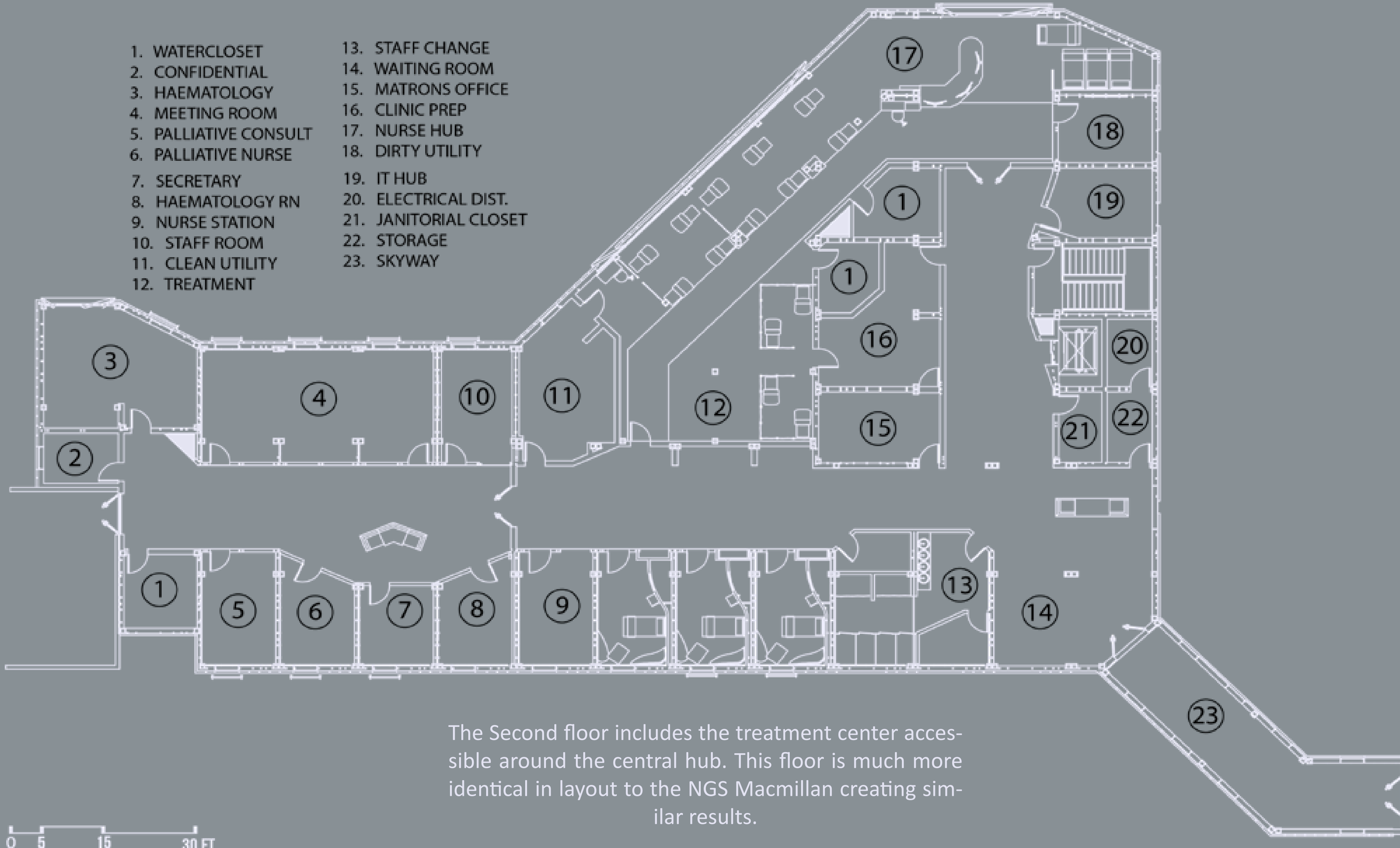
FIRST FLOOR PLAN



Here is the First floor anylogic model complete with circulation paths. Due to the layout of the modular assembly, room organization differs from the existing NGS Macmillan. This resulted in open access to the top exit of the floorplan leading to shortened sink rates. The simplified core proved to be easier to maneuver making access to the lab and reception more efficient.

Figure 96 | First Floor Plan Anylogic Model

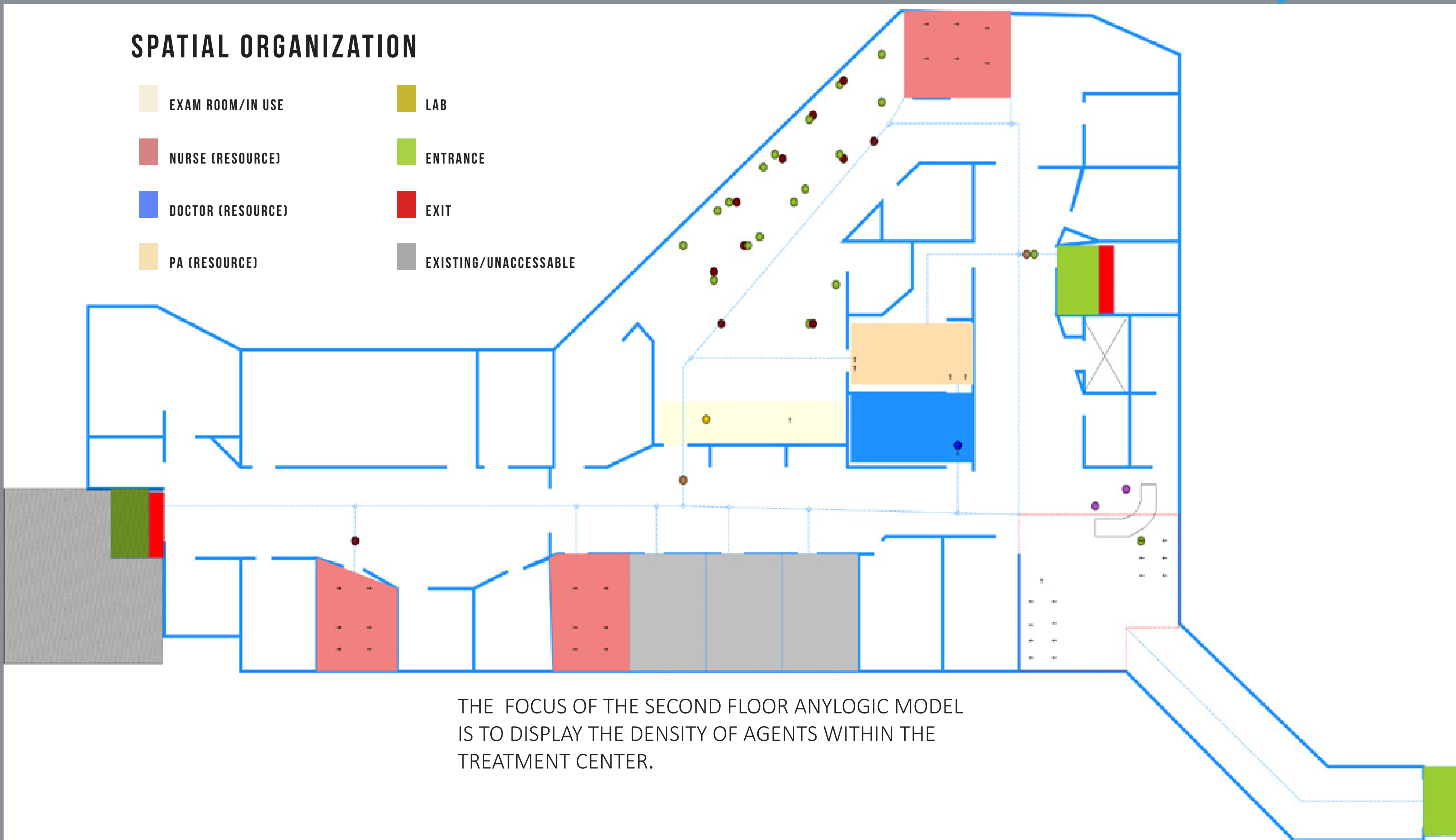
SECOND FLOOR PLAN



The Second floor includes the treatment center accessible around the central hub. This floor is much more identical in layout to the NGS Macmillan creating similar results.

Figure 97 | Second Floor Plan

SECOND FLOOR PLAN



THE FOCUS OF THE SECOND FLOOR ANYLOGIC MODEL IS TO DISPLAY THE DENSITY OF AGENTS WITHIN THE TREATMENT CENTER.

RECEPTIONIST | PATIENT | NURSE (RN) | DOCTOR | PA | LAB TECHNICIAN

Figure 98 | Second Floor Plan Anylogic Model

RESULTS

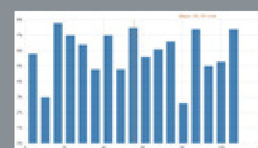
The final results from the AnyLogic models are displayed below as an average or accompanied by a visual aid:

NGS MACMILLAN UNIT

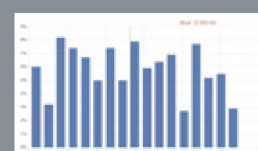
FULL LENGTH ETA (E/W) (6.2 AR):
Distance (m) - 51.52
ETA (sec.) - 78.128

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

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



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



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 - 5.55

MODULAR TWIN

FULL LENGTH ETA (E/W) (6.2
Distance (m) - 50.02
ETA (sec.) - 74.188

FULL LENGTH ETA (N/S) (6.2 AR):
Distance (m) - 16.1
ETA (sec.) - 21.05

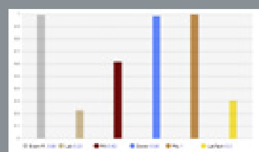
LENGTH OF STAY RESULTS (6.2 AR):
Day - 50.91 min.
Week - 51.43 min.
Month - 53.65 min

LENGTH OF STAY RESULTS (6.5):
Day - 52.486min.
Week - 53.111 min.
Month - 55.621 min

EXAM ROOM UTILIZATION (6.2 AR):
Day - 73 Units
Week - 519 Units
Month (30 Days) - 2144 Units

DOCTOR UTILIZATION (6.2 AR)
Patients per hour - 6.05

UTILIZATION RESULTS (6.2 AR):



NGS

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

PA UTILIZATION (6.2 AR):
Patients per hour - 5.5

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

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

MT

LAB UTILIZATION (6.2 AR):
Day - 17 Units
Week - 119 Units
Month (30 Days) - 488 Units

PA UTILIZATION (6.2 AR):
Patients per hour - 6.5

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

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

CONCLUSION

By comparison, The Modular Twin outperforms the NGS Macmillan unit in circulation and efficiency, but not by much. However, the seemingly insignificant seconds or minutes equate to something greater. When comparing the utilization results of the Doctors and Physicians assistants, it is worth noting that, in both cases, The Modular Twin uses architecture to treat more patients per hour, possibly saving lives.

Having created a standardized Anylogic simulation to determine the efficiency of building circulation, the two structure's results indicate that modular construction was more efficient. The most recognizable attribution was the unavoidable close proximity of spaces in a modular layout. Having parameters set at 52' x 13' x 13', the distance between rooms was shortened. This limitation also caused the relocation of several room types. The angular walls of the Modular Twin in comparison to the NGS Macmillan remained relatively the same despite preconceived notions. In conclusion, through the process of replicating a building using strictly modular methods, the structure was successful in achieving aesthetic likeness, building program, creativity, and efficiency.

The Term efficacy is defined as the ability to produce a desired or intended result. In my Qualitative research, the Design, Quality, and intent of the Modular twin directs patients through a series of transitions designed to improve their well being and overall health. In my Quantitative Research, my proposed design solution outperformed the existing unit, further solidifying its success in producing efficacious results.

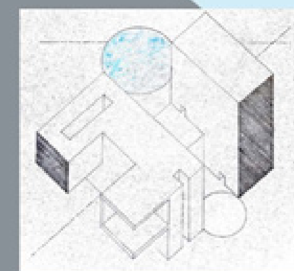
DIGITAL PRESENTATION

THE EFFICACY OF MODULAR DESIGN IN HEALTHCARE

THE EXPLORATION OF MODULAR DESIGN IN HEALTHCARE THROUGH THE COMPARATIVE ANALYSIS OF A TRADITIONALLY CONSTRUCTED HOSPITAL AND ITS MODULAR TWIN

INTRODUCTION

Modular design has become an industry leading philosophy for the future of community-based health services. Modular construction 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, minimal impact, re-use, and modification. This process contradicts traditional construction, pre-fabricating spaces off site to be assembled later. Through correlational research and simulation software, products of modular and traditional construction methods can be compared using operational statistics. The purpose of this thesis is to study the efficacy of the current method of modularity among the industry with intention to refine the process for a safer, enjoyable, more efficient, and replicable solution.



RISE MODULAR

OWATANNA, MINNESOTA

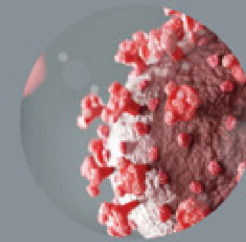
ALVERA APARTMENTS` - MODULAR MULTIFAMILY

DYNAMIC

ST. PAUL, MINNESOTA

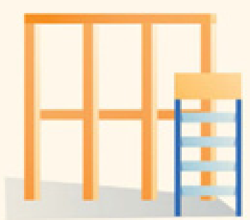
BACKGROUND

In practice, the study, and design of Healthcare Architecture; 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 occupancy of hospitals are determined by the standard daily limit of a unit's typology. When a public health crisis occurs, this leaves hospitals without proper facilities for the influx of patient care. The first solution is expansion, often times in the form of permanent construction with the risk of vacancy when the crisis subsides. The sudden unbalance of supply and demand fuels the risk of panic-architecture. A fast paced solution to a problem with a high likelihood of error and often times patient discomfort results. The Modular Twin to the NGS Macmillan Unit proposes an idea that expansion is still achievable without the need for panic, discomfort, or waste. Modular architecture is not a new development in the field. Originally intended for residential design, It has expanded its purpose on a commercial scale.



Lowering the time of construction, design development and planning, efficient growth is achievable in emergencies like the pandemic. In the process, architects will be tasked with designing these mods, similar to a product patent that can be later repurposed to continue its line for expansion. The on-site construction is reduced to a short assembly with little noise and environmental pollution. Patients in attendance during these times will be subjected to less stressful situations and noise which will ultimately promote recovery.

PRELIMINARY RESEARCH



During **construction,** modular buildings **waste fewer materials** and **use less energy.**

On the **building site,** modular construction **eliminates hazards,** reducing the risk of injuries.

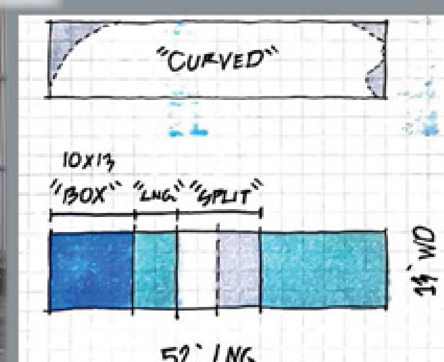
Modular buildings have a **long life span** and can be **reused or reconfigured** for new projects.

A MODULAR UNIT ITSELF IS A STRUCTURAL SYSTEM

WITH A CORNER POST SUPPORTED MODULAR UNIT ASSEMBLED WITH A BOLTED MARRIAGE JOINT, 6 TO 10 STOREYS CAN BE ACHIEVED

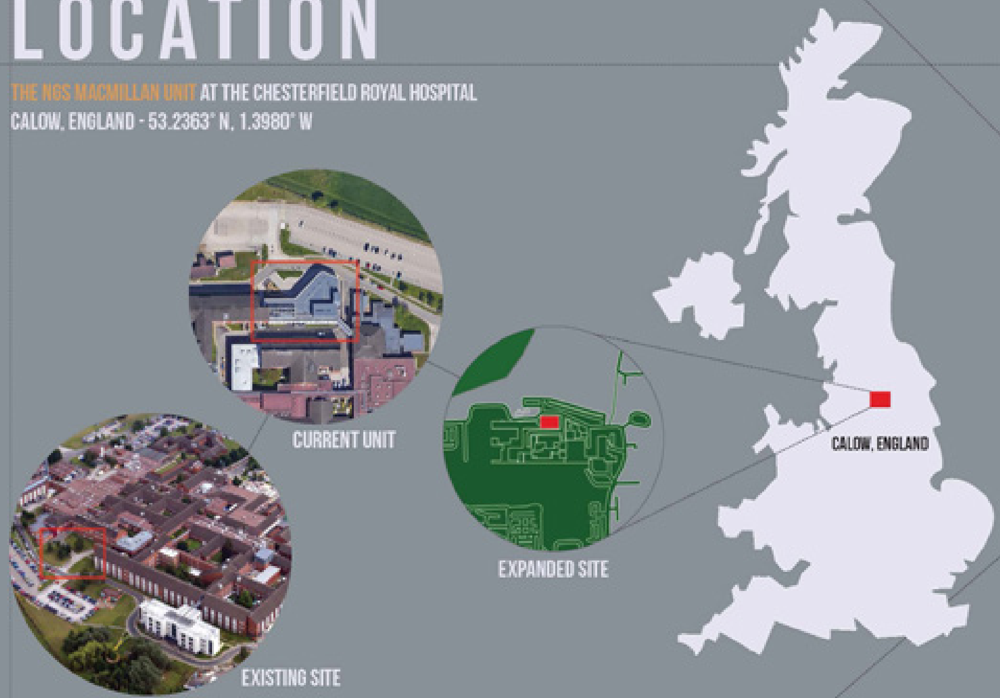
TRANSPORTATION DRIVES UNIT PARAMETERS

MODULAR ARCHITECTURE HAS THE POTENTIAL FOR A 50% REDUCTION IN MATERIAL WASTE AND TIME-TO-BUILD EFFICIENCY



LOCATION

THE NGS MACMILLAN UNIT AT THE CHESTERFIELD ROYAL HOSPITAL
CALOW, ENGLAND - 53.2363° N, 1.3980° W



CORRELATIONAL STUDY:

NGS MACMILLAN UNIT | CHESTERFIELD, UK

PROJECT DESCRIPTION:

YEAR:	2017
ARCHITECT:	The Manser Practice
LOCATION:	Calow, UK
BUSINESS UNIT:	Healthcare
PHOTOGRAPHS:	Hufton + Crow
AWARDS:	RIBA East Midlands Building of the Year
CONSTRUCTION:	Traditional (£ 10m)
SIZE:	2,140 SQ. M. 23,034 SQFT.

PROJECT TYPOLOGY

The NGS Macmillan Unit is a standard ambulatory and cancer patient 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 pre-fabricated construction methods. Its unique spatial organization and envelope are a great representation of the possibilities provided by traditional construction. Reaching the limits of an organic facade while maintaining high efficiency, it is the perfect sample to be tested.

Materiality

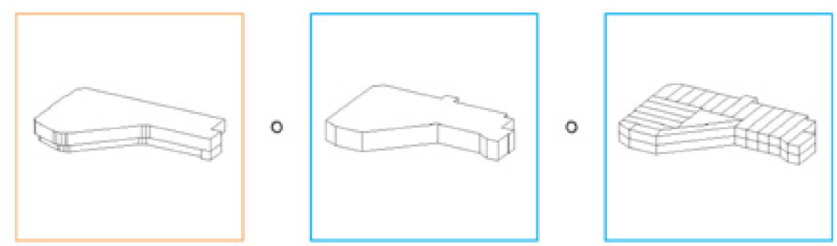
Healthcare facilities require an abundance of specific materials to maintain a sterile environment, provide safe passage and avoid contamination from units such as labs and X-rays. These are standardized and universal materials, however, the facade has more creative freedom. This would provide a challenge to create a design solution that not only functions internally but also captures the dynamic aesthetic of the NGS Macmillan's envelope. Utilizing the verticality of the seams between modular units, a similar effect can be drawn from the external fins on the existing facility. Window placement, white façade paneling and elbow shape all embody the characteristics of the form originally designed by The Manser Practice.

PROJECT GOALS

EF•FI•CA•CY | *noun*
the ability to produce a desired or intended result

SITE PLAN

ORGANIZATIONAL MASSING

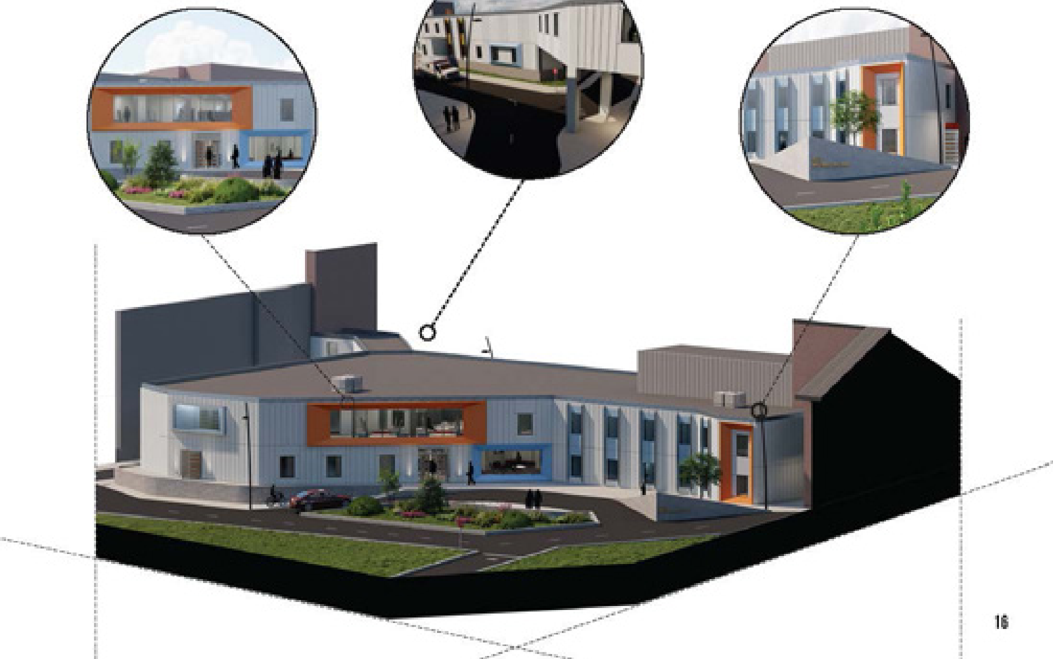


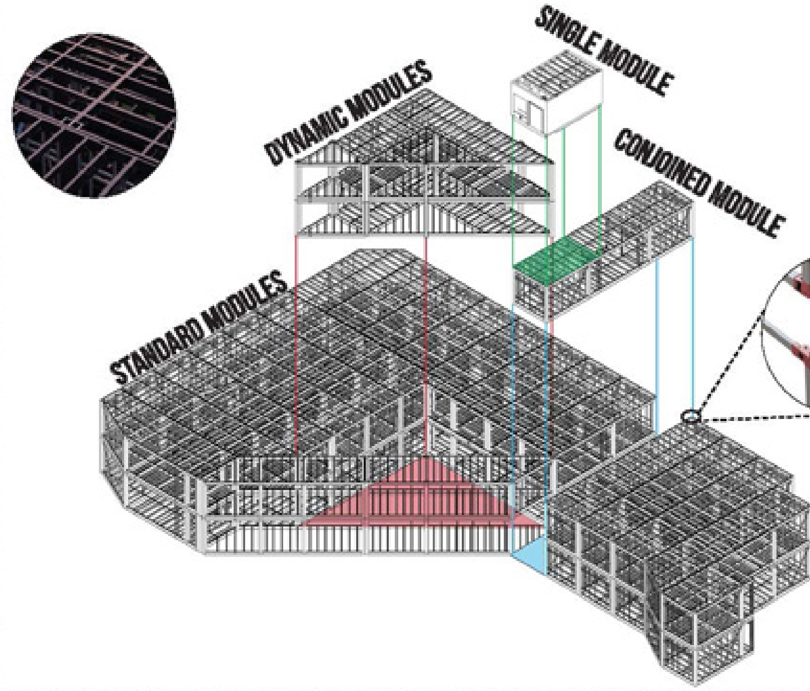
NGS MACMILLAN

MODULAR TWIN

FULL UNIT ASSEMBLY

COMPLETED CONSTRUCTION



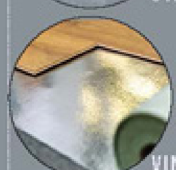


COMPLETE STRUCTURAL ASSEMBLY

INDIVIDUAL UNIT ASSEMBLY

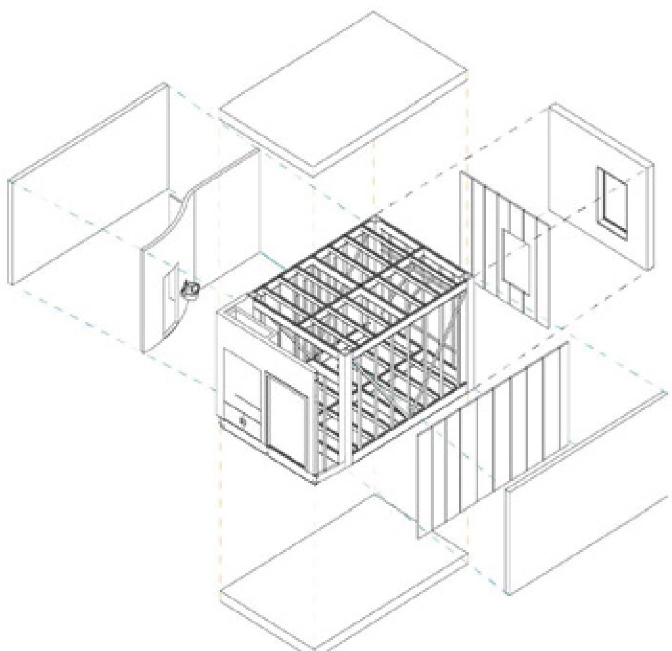
ALUMINUM

STEEL

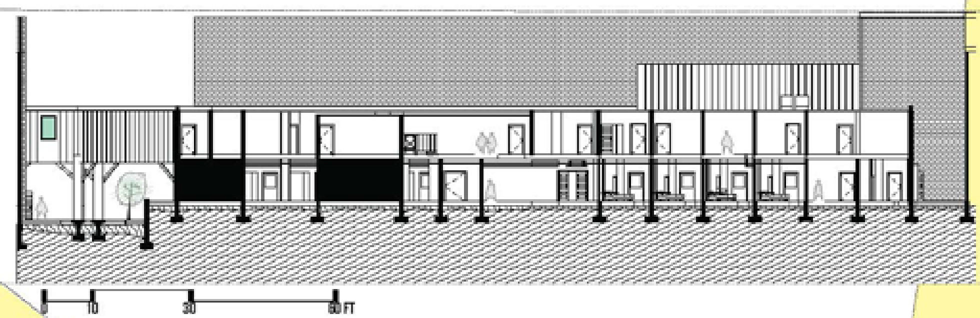


VINYL

PVC

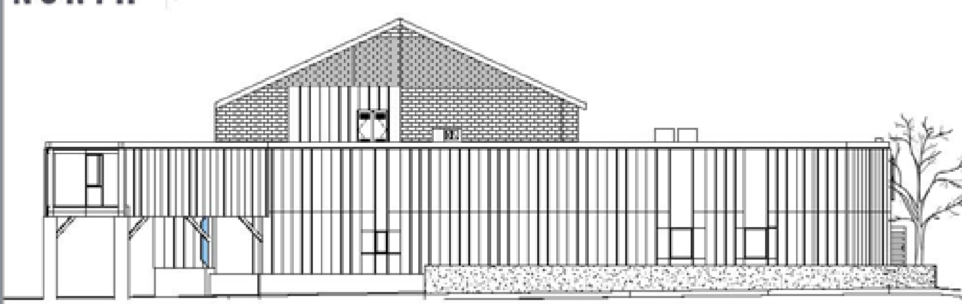


SECTION CUT



ELEVATIONS

NORTH



EAST

SOUTH

WEST

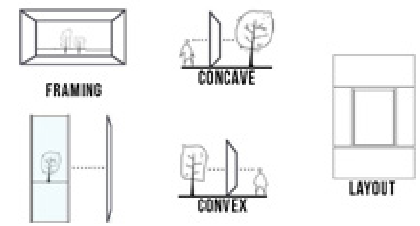
DESIGN ELEMENTS

NORTHWEST - MAIN ENTRANCE

The Modular Twin's design philosophy takes subtle influence from its traditional counterpart, further solidifying the theoretical instance where it could be designed by The Manser Practice.

COLOR THEORY

- Pureness, Cleanliness, Productivity, Trust
- Positivity, Creativity, Energy, Happiness
- Confidence, Passion, Warmth, Power

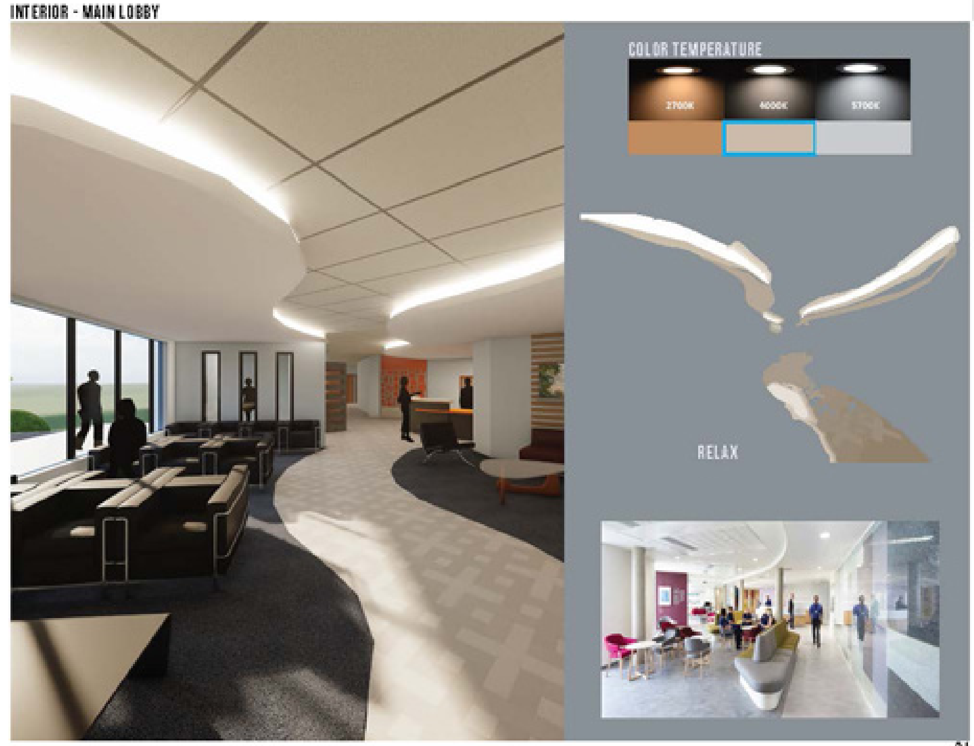


NORTHWEST - MAIN ENTRANCE

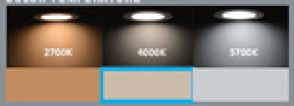
INTERIOR - PRIMARY CORRIDOR

INTERIOR - STANDARD EXAM ROOM

INTERIOR - MAIN LOBBY



COLOR TEMPERATURE



DIRECT

COLOR THEORY

ANYLOGIC

SIMULATION START

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, a comparison of the results can be conducted from the existing and theoretical designs, both traditional and modular. The completion of these simulations will address which design solution(s) 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

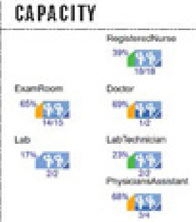
anylogic®

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

SPATIAL ORGANIZATION

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

CAPACITY



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.

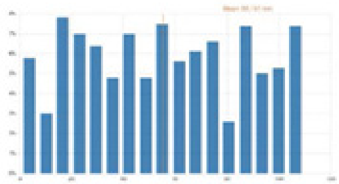
RECEPTIONIST — PATIENT — NURSE (RN) — DOCTOR — PA — LAB TECHNICIAN

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.

PROCESS LOGIC - MAIN

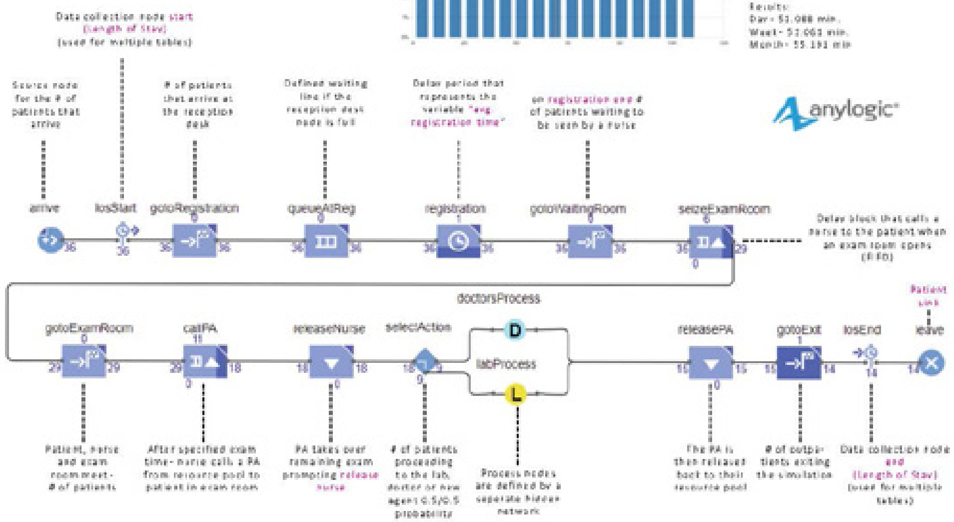
The logic or block code of the simulation is displayed below. Here is where the order of operations is defined. The goal of this logic network was to establish a core/generic tree that can be replicated to other models. The produced results will be the control variable for the proposed modular structure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



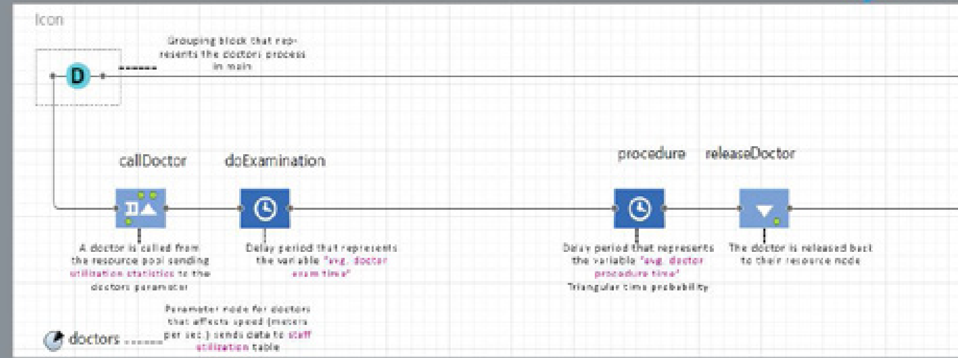
LENGTH OF STAY

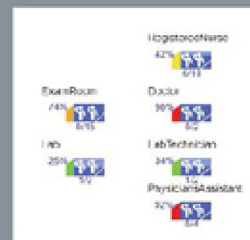
Measures the patients Length of Stay at the clinic from the first data collection node at the start of the process to the second data collection node once the patient reaches the exit door.

Results:
Day - 53.088 min.
Week - 53.063 min.
Month - 55.191 min



DOCTORS PROCESS



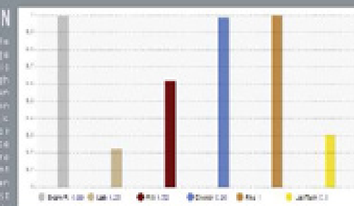


RESOURCE BLOCK

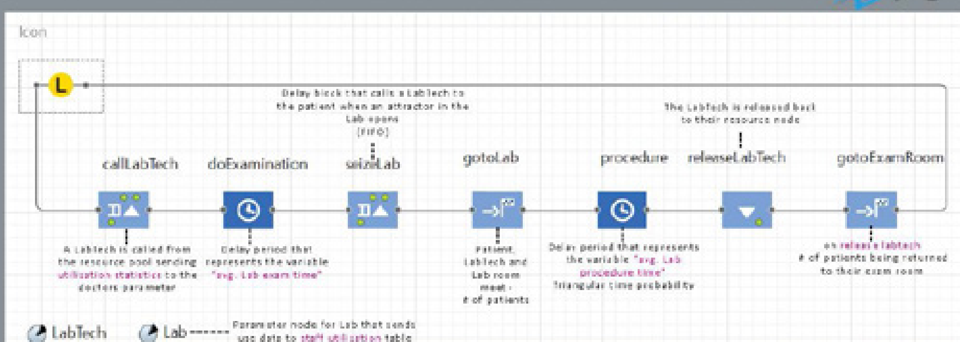
Resource blocks are grouping nodes that represent a resource pool of a particular agent. In this case the Doctor resource block is being utilized to seize an exam room, perform an exam, perform a procedure and then return to its resource node within the model. Resource blocks can work with data sets 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 utilization) 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.

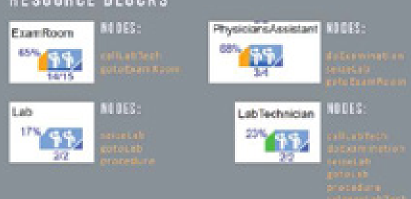


LAB PROCESS

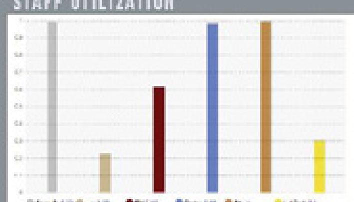


Parameter node for Lab Technicians that affects speed (meters per sec.) sends data to staff utilization table

RESOURCE BLOCKS

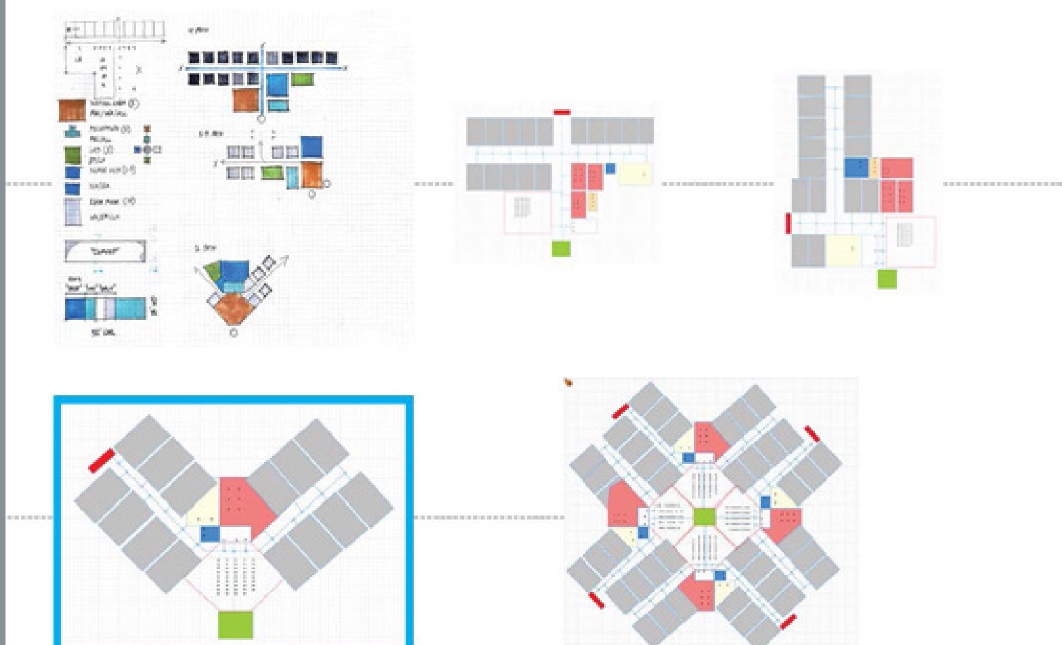


STAFF UTILIZATION

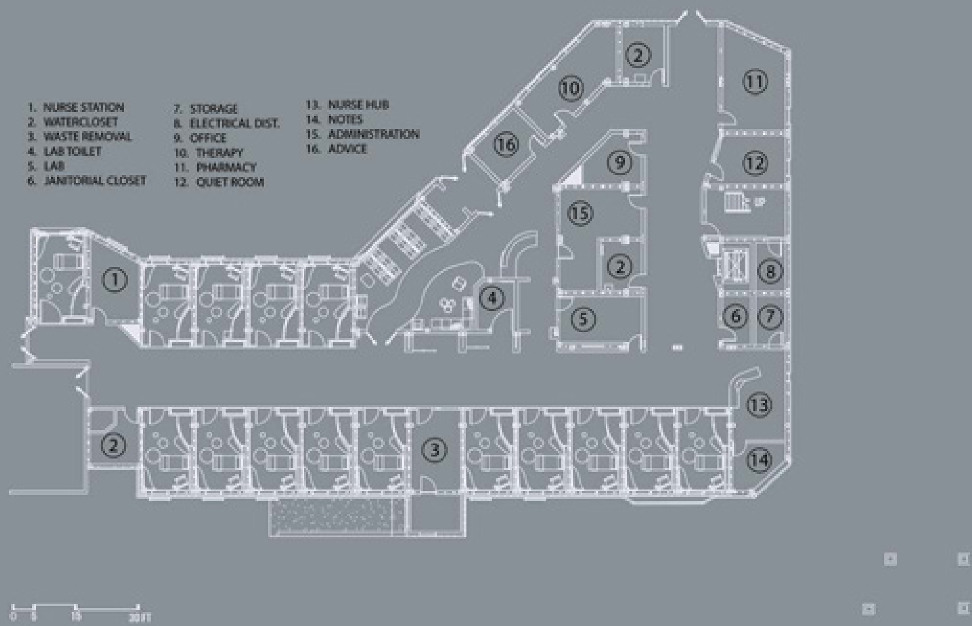


The staff utilization table measures the percent usage of a particular agent. These variables should remain relatively the same across every seperately run simulation. Variables change with arrival rate parameters.

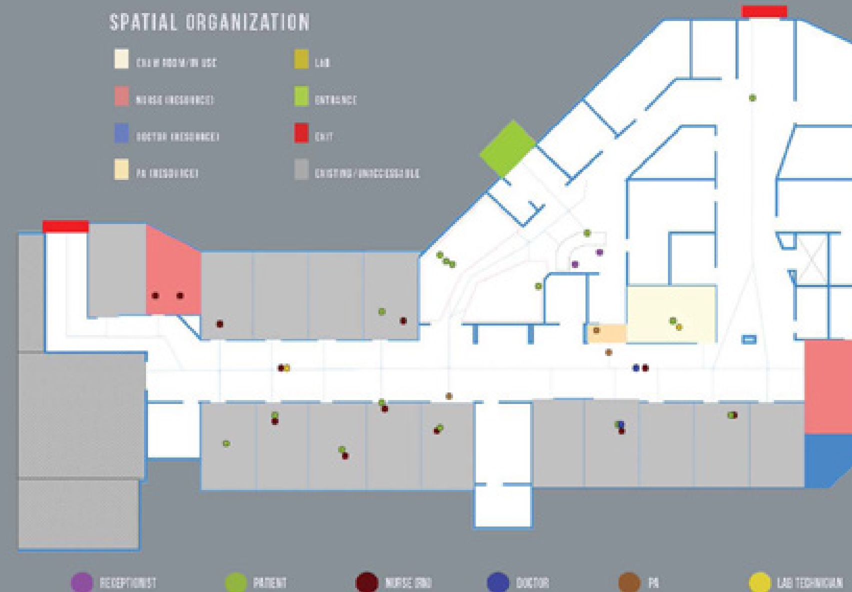
PROCESS OF ORGANIZATION



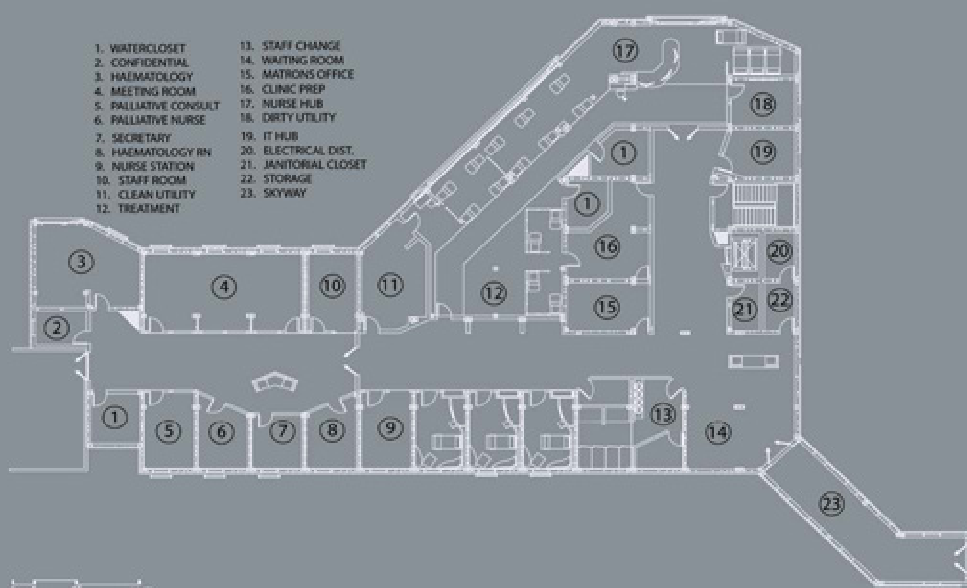
FIRST FLOOR PLAN



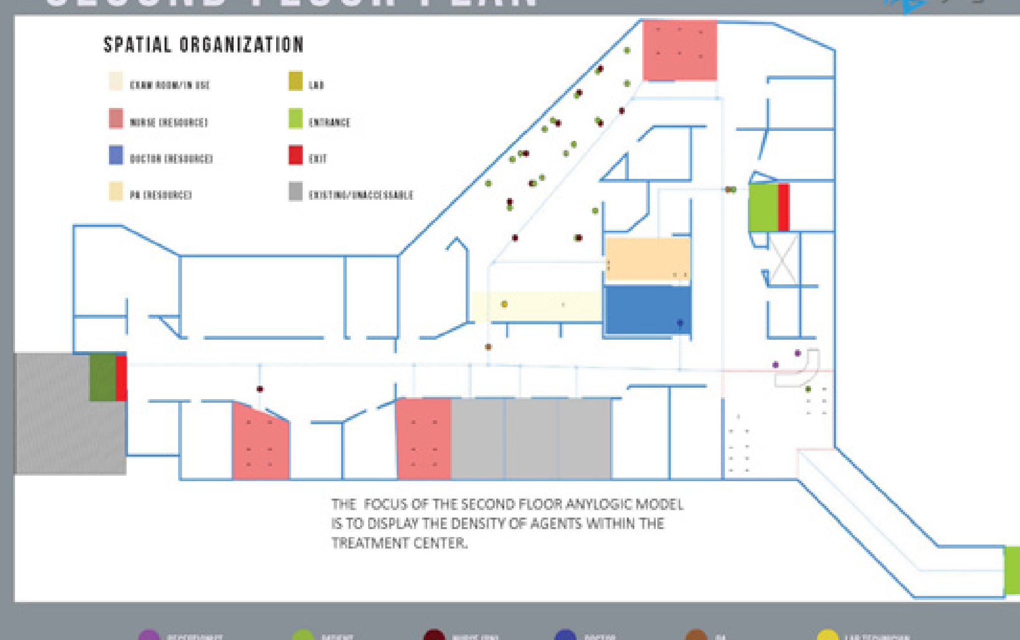
FIRST FLOOR PLAN



SECOND FLOOR PLAN



SECOND FLOOR PLAN

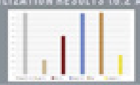


THE FOCUS OF THE SECOND FLOOR ANYLOGIC MODEL IS TO DISPLAY THE DENSITY OF AGENTS WITHIN THE TREATMENT CENTER.

RESULTS

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

UTILIZATION RESULTS (6.2 AR):



NGS

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

PA UTILIZATION (6.2 AR):
Patients per hour - 5.5

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

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

MT

LAB UTILIZATION (6.2 AR):
Day - 17 Units
Week - 119 Units
Month (30 Days) - 488 Units

PA UTILIZATION (6.2 AR):
Patients per hour - 6.5

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

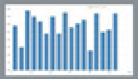
LABTECH UTILIZATION (6.2 AR):
Patients per hour - 10.95

NGS MACMILLAN UNIT

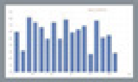
FULL LENGTH ETA (E/W) (6.2 AR):
Distance (m) - 51.52
ETA (sec.) - 78.128

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

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



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



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 - 5.55

MODULAR TWIN

FULL LENGTH ETA (E/W) (6.2
Distance (m) - 50.02
ETA (sec.) - 74.188

FULL LENGTH ETA (N/S) (6.2 AR):
Distance (m) - 16.1
ETA (sec.) - 21.05

LENGTH OF STAY RESULTS (6.2 AR):
Day - 50.91 min.
Week - 51.43 min.
Month - 53.65 min

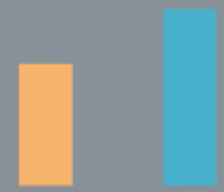
LENGTH OF STAY RESULTS (6.5):
Day - 52.486min.
Week - 53.111 min.
Month - 55.621 min

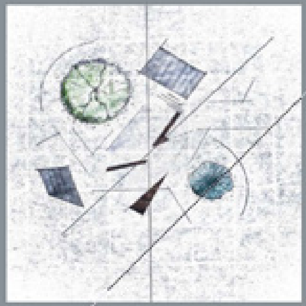
EXAM ROOM UTILIZATION (6.2 AR):
Day - 73 Units
Week - 519 Units
Month (30 Days) - 2144 Units

DOCTOR UTILIZATION (6.2 AR)
Patients per hour - 6.05

CONCLUSION

Having created a standardized Anylogic simulation to determine the efficiency of building circulation, the two structure's results indicate that modular construction was more efficient. The most recognizable attribution was the unavoidable close proximity of spaces in a modular layout. Having parameters set at 52' x 13' x 13', the distance between rooms was shortened. This limitation also caused the relocation of several room types. The angular walls of the Modular Twin in comparison to the NGS Macmillan remained relatively the same despite preconceived notions. In conclusion, through the process of replicating a building using strictly modular methods, the structure was successful in achieving aesthetic likeness, building program, creativity, and efficiency.





THANK YOU

Ganapathy Mahalingam
Cindy Urness
Laura C. Jones
My Peers
My Parents
My Friends

EXHIBIT
&
BOARDS

Figure 99 | Thesis Exhibit

Figure 100 | Thesis Boards

Figure 101 | Physical Model - Process 1

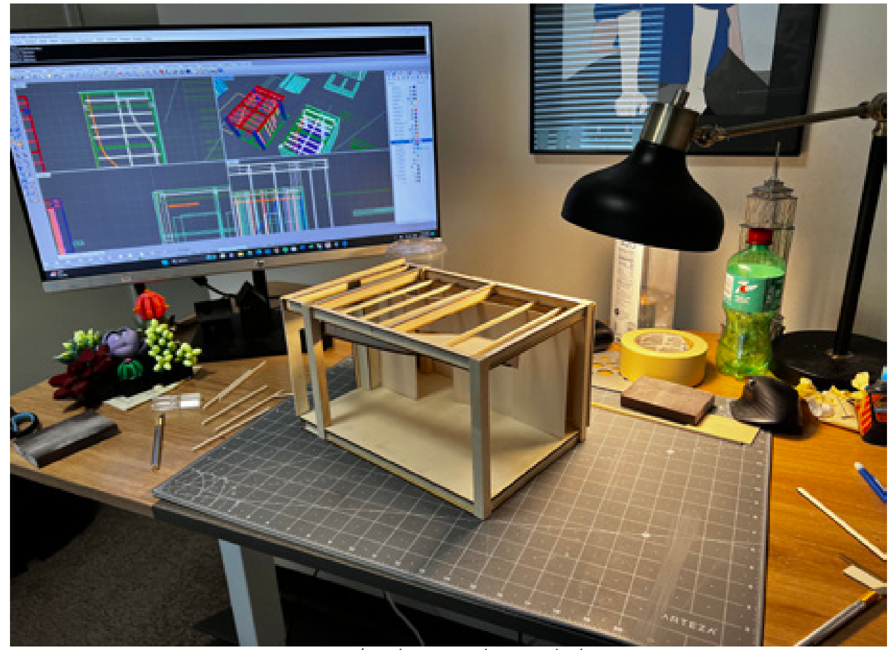


Figure 102 | Physical Model - Process 2

Figure 103 | Physical Model - Process 3

Figure 104 | Physical Model - Process 4

RESEARCH APPENDIX:

Interview with F9 Productions:

Two partners from F9 Productions in Colorado, Lance Cayko and Alex Gore met with me to discuss their experience with architecture in Colorado and Loveland near one of my case study's site, their experience with modular construction and to discuss the client demographic and client needs of Colorado.

Important notes:

Modular construction is primarily found in residential projects more so than commercial- even in healthcare.

The bottom line of every project is cost and modular construction as an option for many projects is more expensive in urban environments than in rural and mountainous terrain. This is because construction has a short shelf life where it is only allowed from May until September before the winter months make it too dangerous to continue.

The typical proejct that a client requests is defined in order by Time/Money/Program. Time is the primary worry and is something that modular construction excels in. The secondary trait of modular construction in these areas is sustainability which is entirely dependant on location. For example, Denver had placed a requirement for solar panels and incentivized sustainable construction so a client would have potential to benefit in the long run using modular construciton in urban areas.

Locations that preference modular construction: the mountain range following Winter park to Granby.

Closing notes: Architecture in Colorado is primarily driven by cost rather and sustainable values, however, time to build efficiency shares this same level of importance. The bottom line is finding a client that prefences this efficiency to be able to utilize modular construction. The cost is slightly higher, but with events such as COVID, the mindset is steadily changing.

Lance and Alex also provided key leads in continuing my research including architects within the field and professionals in modular construction.

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PREVIOUS STUDIO EXPERIENCE:

2ND YEAR

FALL 2019

INSTRUCTOR	EMILY GUO
PROJECT	MINNEAPOLIS ROWING CLUB
TYPOLOGY	COMMUNITY BOATHOUSE

SPRING 2020

INSTRUCTOR	MILTON YERGENS
PROJECT	JONES RESIDENCE
TYPOLOGY	RESIDENTIAL

3RD YEAR

FALL 2020

INSTRUCTOR	BAKR M. ALY AHMED
PROJECT	OLYMPIC RESORT
TYPOLOGY	RECEPTION AND EVENT CENTER

SPRING 2021

INSTRUCTOR	PAUL GLEYE
PROJECT	ETHIOPIAN CULTURAL INSIGHT CENTER
TYPOLOGY	EVENT CENTER

4TH YEAR

FALL 2021

INSTRUCTOR	CINDY URNESS
PROJECT	SUSTAINABLE MIAMI HIGH RISE
TYPOLOGY	HIGHRISE CAPSTONE PROJECT

SPRING 2022

INSTRUCTOR	AMAR HUSSEIN
PROJECT	FLORIDA DEVELOPMENT PROJECT
TYPOLOGY	URBAN DEVELOPMENT