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WHERE RESEARCH MEETS DESIGN: Using parametric modeling to optimize walking distances and enhance workflow

ABSTRACT

There is a growing body of evidence on the impact of design on human health and wellbeing, and incorporating this in innovative ways can aid the design process making it more efficient, precise and predictive of desired outcomes. Evidence-based knowledge related to walking distance has been implemented to derive parameters for optimizing future healthcare facilities. A path finding algorithm was developed using Rhino/Grasshopper in order to calculate walking distances between each two spaces and to simulate total walking distances for nurses over their working shifts.

The generated parametric model enables the project team to precisely analyze and evaluate design options earlier and faster in the process. It also allows optimization of design configurations using parameters derived from available evidence related to healthy workplaces in hospitals. Clear identification of key parameters that impact outcomes and the use of parametric modeling techniques to allow intentional manipulation of these parameters to achieve desired outcomes, allows the client and design team to see the consequences of design decisions prior to construction.

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1.0 BACKGROUND

There is an extensive body of literature on how nurses spend their time, the extensive distances they walk, and the need to optimize these distances. A detailed review of this literature can be found in Pati, et al. (2012), Zadeh, et al. (2012) and Hendrich, et al. (2009). With increasing sizes of patient rooms, building code requirements for patient room windows on the perimeter, and the push on patient-centered care- all of which are valid and supported by evidence - an unintended outcome has been the size of core of the inpatient units. Key services and support spaces are relegated to an ever-fattening core, and complex issues around adjacencies and proximities have to be resolved under very tight constraints. The resolution of the core has become more than a design problem; it is now a computational problem, and one can simultaneously account for multiple dynamic factors to arrive at an optimal solution. In this paper, we will share how parametric modeling can be used as a tool to create healthy workplaces for nurses in inpatient units by optimizing walking distances and workflows. We will also share a specific case study comparing decentralized and centralized nursing units, and demonstrate how plan analytics can serve as a valuable research tool.

Parametric Modeling. Parametric modeling is the act of designing a process rather than a form. Traditionally modeled forms are immutable. The only way to change the form is through redesign. However, with parametric modeling we design a reusable and configurable process. By defining relationships between inputs, decisions and actions a nearly infinite number of variations can be created from one set of rules. In addition to architecture and construction, many other industries use parametric modeling including industrial design, manufacturing, aerospace and even guitar manufacturers. Almost all manufacturing and design industries benefit from the repeatable high precision parts parametric modeling can create. Integrating a parametric model with testing and simulation provides even further benefits. Forms can rapidly be optimized using parametric models to quickly create, test and compare multiple options.

Theoretical Framework. Assuming that patient care is the key purpose of any inpatient unit, and workflow is centered around patient care, in this paper we confined our discussion to travel distances from a patient room to:

- Medication room
- Clean Utility room
- Soiled Utility room
- Equipment Holding room
- Crash Cart alcoves
- Documentation Station(s)
- Nourishment room

It is important to mention that care coordination between the clinical care team and ancillary teams is absolutely critical, however, that is not discussed within the scope of this paper. The paper is based on addressing distances between key rooms as a driver for healthcare performance as shown in Figure 1. The purpose is to use parametric modeling as a tool, during the design process, to enable the translation of the driver into the three levels of outcomes (driven) by the design, in real time. We will focus on level 1 and discuss benchmarking data that is needed to translate level 1 to level 2 and 3 outcomes. The ability to see the operational consequences of our design decisions in real time is one of the biggest advantages of using parametric modeling. The main objective is to solve healthcare challenges (e.g. wasteful walking) by using advanced analytical and modeling tools during the design process, thus ingraining research thinking into design early on.

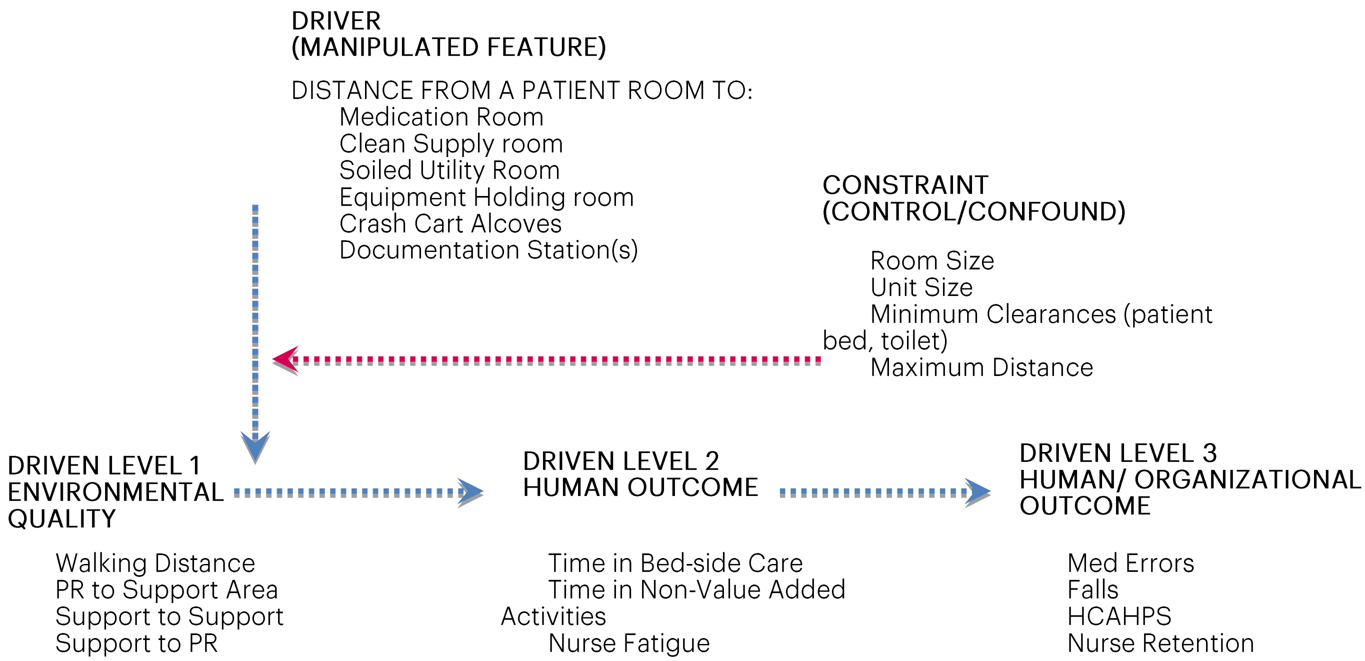
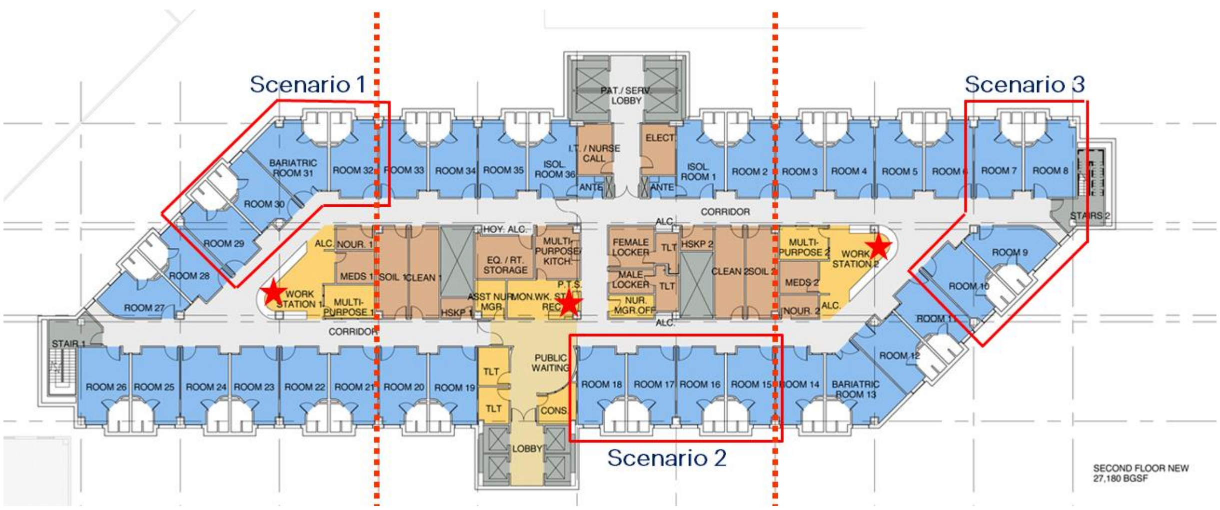


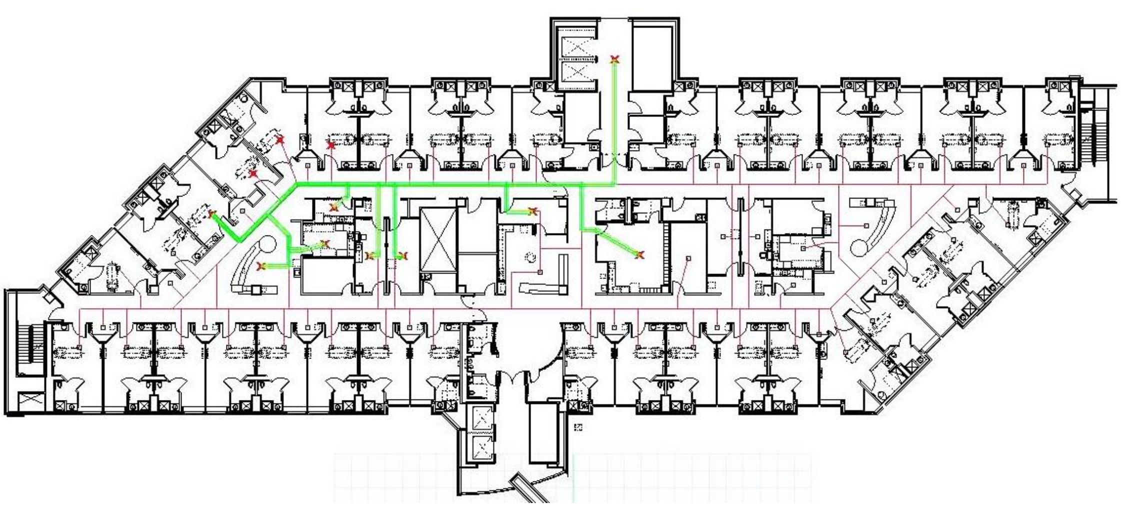
Figure 1. Theoretical Framework for Design and Outcome (Source: Nanda, 2013; CADRE)

2.0 CASE STUDY

To test the tool, a class project was undertaken in collaboration with Texas A&M University, to tap into the analytical piece. The objective of this project was to implement evidence-based knowledge to derive parameters for comparing nurse's walking distances in centralized vs. decentralized nursing units in healthcare facilities. Based on relevant and reliable evidence, potential variables were developed and used as driver, driven and constraining parameters to define different operations for a set of basic functions in a parametric design tool (Monedero, 2000; Sabra & Mullins, 2011). The Methodist Charlton Hospital in Dallas, TX, designed by HKS Architects, was selected as the case study for this project. Each nursing unit in this hospital has 36 patient rooms, three centralized, and 18 decentralized nursing stations. Based on the fact that one nurse is normally responsible for 4-6 patients in medical-surgical units (Tevington, 2011), three different scenarios were defined for this parametric model. In each scenario, four patient rooms, one central and two decentralized nursing stations were selected in order to compare the walking distances for a nurse when working from centralized vs. decentralized stations.

A path finding Grasshopper model (an algorithm integrated with Rhino's 3-D modeling tools) was developed for simulating one shift work of activity for a nurse, in order to calculate the walking distance. The model consists of a network of corridor routes and the main nurse destinations from patient rooms. Dijkstra's shortest path algorithm was implemented as the best known and robust algorithm for this problem both in theory and practice (Goldberg & Tarjan, 1996). This algorithm can find the shortest path in a network of nodes and paths when the start and end nodes are given. The input for this model was provided by a research project conducted by HKS Architects, on nurse walking patterns, including their main destinations from patient rooms, the maximum distances, and the frequency of roundtrips per primary shift (see Table 1). This data has been used in this Grasshopper model in order to calculate the shortest walk for each scenario with centralized vs. decentralized nursing stations.





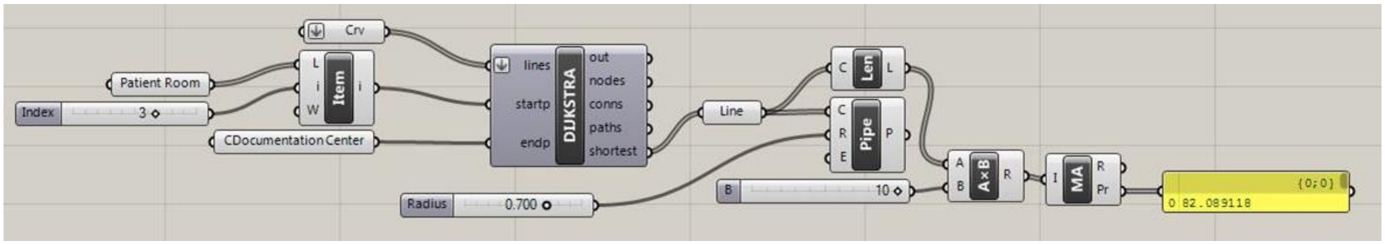


Table 1. Round trip and distance parameters for nurse travel from patient rooms

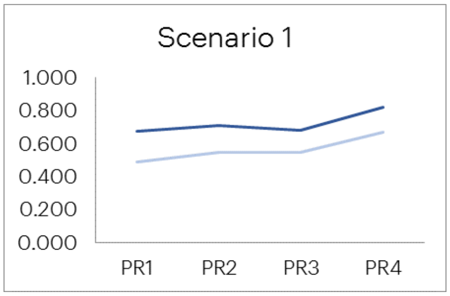
Location	Activity	Minimum Roundtrips per Primary Shift[1]
Documentation Station(s)	Documentation Consultation/Collaboration Socialization	10.0
Medication Room	Meds Management/Admin Med Prep Med Supply Acquisition	5.0
Clean Utility Room	Supply Use Management/Admin Medical Supply Acquisition Clean Linen Acquisition	3.0
Soiled Utility Room	Waste Disposal Dirty Equipment Holding Soiled Linen Holding	2.0
Equipment Holding Room	Equipment Storage Broken Equipment Holding	1.0
Nourishment Room - Meals	Food Tray Hold/Retrieval Used Tray Holding	3.0
Nourishment Room - Ice/Snacks	Snack/Drink Acquisition Ice Pack Acquisition	4.0
Break Room	Personal Effects Access/Toilet Education Respite	3.0
Patient Transport (Service Elevators)	Link to Surgery, Imaging, Other D&T Link to other Bed Units Link to Discharge (Lobby)	0.2

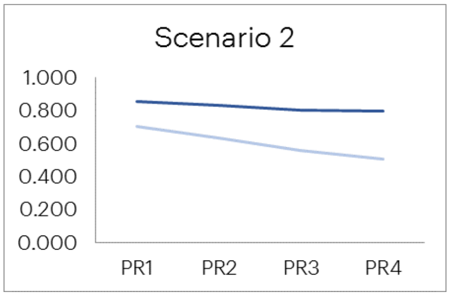
[1]These figures are theoretical assumptions for purposes of this study. Actual trip counts measured through shadowing in the field often show higher frequencies.

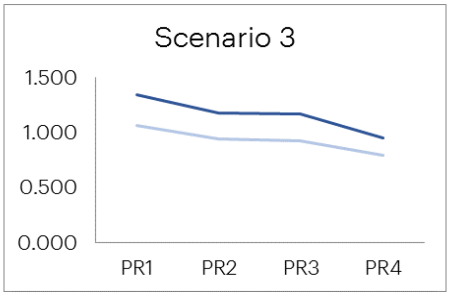
After implementing the simulation of one shift work of activity for a nurse, the shortest path was calculated for each scenario from patient rooms to nurse stations and support areas, while using centralized vs. decentralized nursing stations. The data (miles of walking per shift) was entered and descriptively analyzed in Microsoft Excel (see Table 2). The findings show that travel distances are lower by approximately 20-25% for nurses working from decentralized stations compared with whom working form centralized stations. The result of this project shows that designing nursing units with decentralized stations may have a positive impact on reducing nurses' travel distance. The result implies that providing decentralized nursing stations can improve patient safety and quality of care, by increasing visibility and saving nurses' time for more direct patient care. Shorter nurses' walking distance also implies that this design can help nurses by reducing fatigue and burnout, and improving their work performance and efficiency. This is one example of how better design can help facilities with their bottom-line, by improving nurses work environments which can lead to higher quality of patient care, and enhanced staff, patients and families' satisfaction.

Table 2. Walking Distance for Centralized vs. Decentralized Nurse Stations

		Patient Room 1	Patient Room 2	Patient Room 3	Patient Room 4	TOTAL
Scenario 1	Centralized	0.673	0.708	0.681	0.819	2.881
	Decentralized	0.491	0.549	0.55	0.67	2.26
	% reduced	%27.0	%22.5	%19.2	%18.2	%21.6
Scenario 2	Centralized	0.857	0.831	0.805	0.796	3.289
	Decentralized	0.702	0.635	0.56	0.509	2.407
	% reduced	%18.0	%23.6	%30.4	%36.0	%26.8
Scenario 3	Centralized	1.346	1.183	1.167	0.952	4.647
	Decentralized	1.063	0.942	0.929	0.795	3.729
	% reduced	%21.0	%20.3	%20.4	%16.5	%19.8







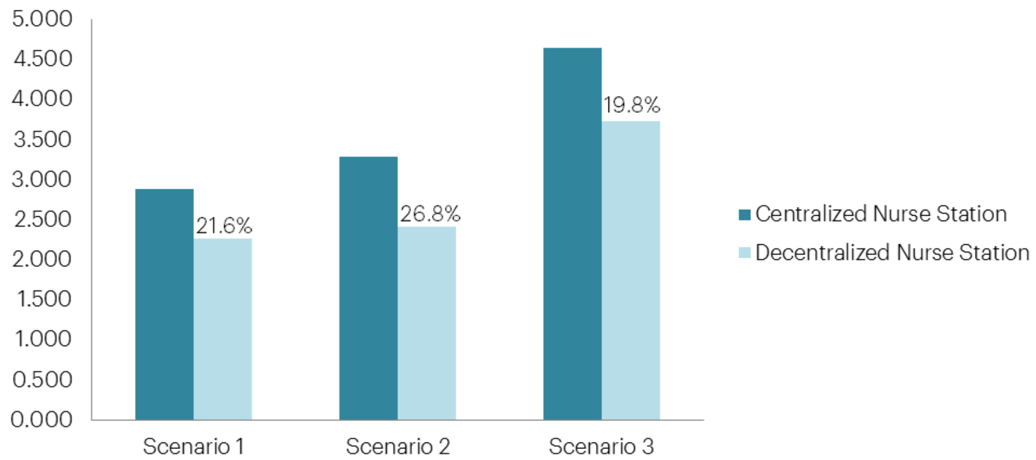


Figure 2. Comparing Walking Distances for Centralized vs. Decentralized Nurse Stations for Three Scenarios

3.0 IMPLEMENTATION IN PRACTICE

Data Capture. At the most basic level, the parametric planning tool evaluates the distances from every room to every other room and returns refined data to help the designer make better decisions. The tool has two sets of inputs. First, lines are drawn to represent center of the hallways. Second, points are placed at the door way of each room to be analyzed. These points are grouped by room type and can also be labeled with room names. While these inputs can be placed by hand, it is even faster to cull the data from an existing Revit floor plan. After the hallways and room data has been created, the parametric tool builds a node network.

Analysis. With the node network complete, the path finding analysis can begin. This analysis uses the Djikstra's algorithm to calculate the shortest path from each room, to every other room. The resulting raw data is a list of the distances between all the rooms in the network. This raw data is then processed further to extract meaningful metrics that designers can quickly read to understand if a change has improved or decrease the performance of the space.

The pivot table in the chart below shows the shortest distance from each patient room in an ongoing project to their closest support spaces. This data can then be summed and sorted to identify the patient rooms with the longest walking distances. Furthermore, by identifying key nurse workflows, such as Patient Room to Nurse Station to Meds, we can evaluate and rank each patient room against commonly used working conditions in the unit. This tool gives designers and planners a much faster iteration cycle to test design choices, understand consequences, and improve building performance. A dynamic link allows analysts to use pivot tables, formulas, and charts to perform more complex evaluations.

Visualization. Visualization techniques such as a heat map can help to translate this data for rapid assimilation by designers. The heat map is a great example of a diagram which allows a designer to quickly read the performance of a layout. Based on the color coding the designer quickly understands which patient rooms, on the Y axis, are too far from the support spaces on the X axis- it provides a quick summary of the efficiency of the design. This process is currently being deployed in a project. Field research provides the data that is informing the parametric analysis which is being incorporated during the design process rather than retrospectively. Results from this study will be shared upon completion.

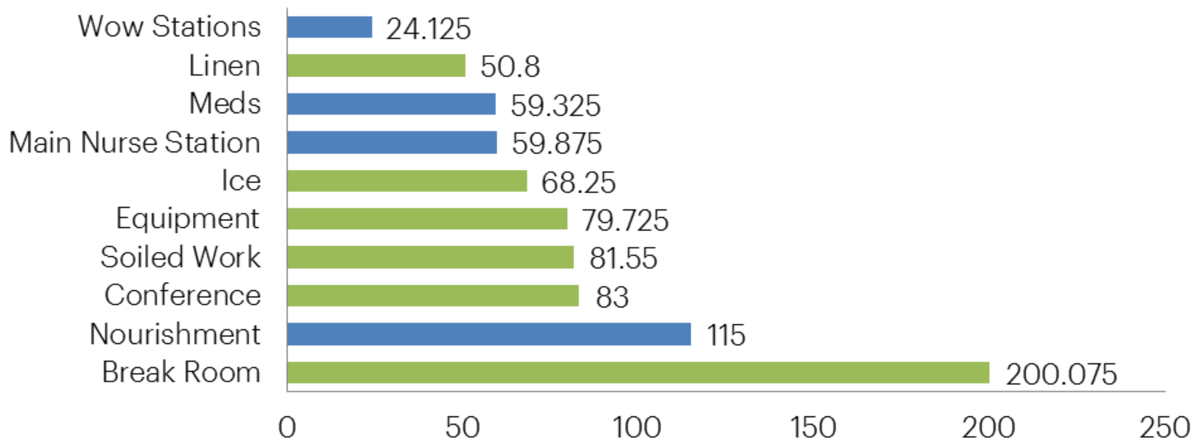


Figure 3. Average Distance from Patient Rooms to Support Spaces

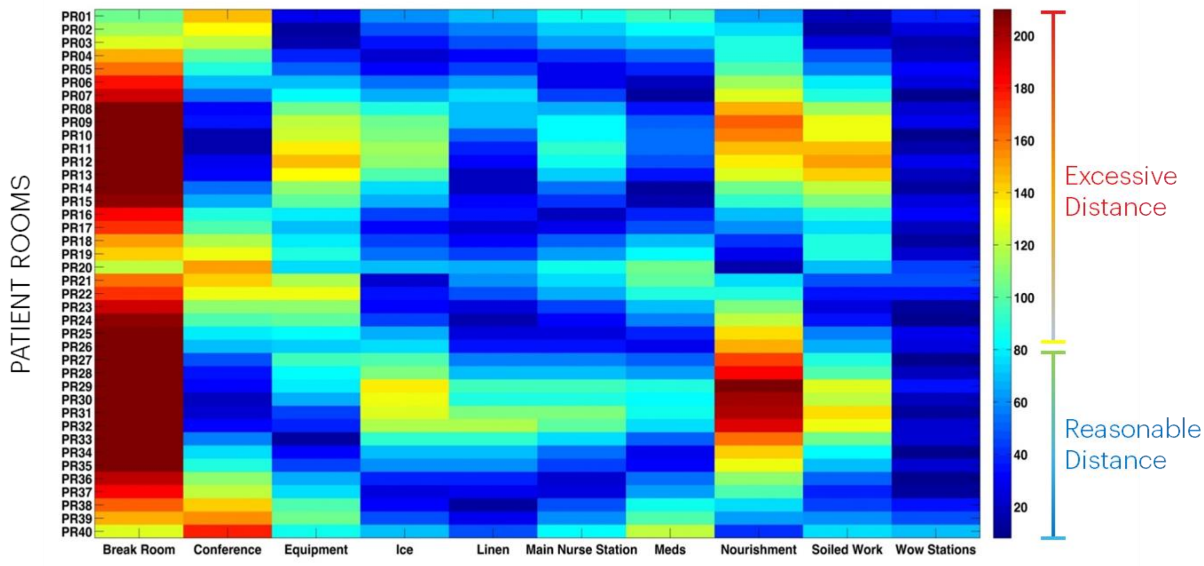


Figure 4. Heat Map of Walking Distances from Each Patient Rooms to Each Support Spaces

4.0 IMPLICATIONS AND FUTURE RESEARCH

Implementing research and analytical tools like parametric analysis within the core design practice allows us to assess the impact of optimized spatial configurations on the design process, and organizational effectiveness, early on. Good design must first and foremost meet the operational objectives of the project owner. In this example of a healthcare building, the patient care activities demand space configurations that facilitate highly efficient workflows with minimal time spent in wasteful walking to provide that care. Significant improvement in the time a nurse can spend with the patient at their bedside has been documented by Pati et al (2012). Hence, the ideal organization of space for internal function then gives form to the building that architects then shape into a comprehensive design solution.

The benefit of this analytical tool, however, goes well beyond rapid evaluation of proposed options in building configuration. Alternative scenarios or what-if studies can be conducted to inform the operational planning and associated space programming that ultimately quantify the design goal. This tool has the capability to educate the building owner as to the value of making certain operational changes that affect design configuration toward improvement of building performance and life cycle cost. Finally, as this tool is further developed, it is expected to assist designers in creating optimal configurations at the outset of design, potentially mitigating repetitive studies of alternatives that often occur in design before the best solution is finally found.

Translating evidence into tools that can be used by architects to inform design or to expedite its process is an imperative for the architectural community. Clear identification of key parameters that impact outcomes and the use of parametric modeling techniques to allow intentional manipulation of these parameters to achieve desired outcomes, allows the client and design team to see the consequences of design decisions prior to construction. The client and design team may then translate these consequences into performance metrics associated with enhanced value of the project, as well as key financial metrics; of project cost (first cost) and long-term operating cost (life cycle).

Optimization of spatial configurations, as an iterative process within a feedback loop during building planning and design, as described in this paper, represents a major milestone in performance-driven design of inpatient bed tower floor plans. Using this analysis tool during the process of design to translate the driver into driven outcomes in a real time workflow affords the planner/designer a much more time-efficient means of simulation. Yet, this type of simulation is still characterized by an iterative cycle of small consecutive feedback loops, which illustrates the direct benefit of computational design to speed the process of analyzing the performance, determining our response, and revising the planning.

While offering us an unprecedented capacity for simulation of iterations, this process represents the first wave of a more intensive 3-part initiative. The next step includes building a tool providing the planner/designer with the ability to set a specific criteria of maximum threshold for walking distances, and input parameters related to the specific site and program to generate geometry within a parametric model. This will allow us to improve the efficiency of the simulation feedback loop by beginning the iterative process with an optimal plan. The third wave will include the use of a genetic solver to automate the process of iteration and allow for hundreds (or thousands) of alternates to be tested against user-defined criteria and sorted for fitness. Optimization through the use of a genetic algorithm in this scenario of generative design will not only speed the process, it will have the ability to provide multiple optimal solutions by testing ideas that might not necessarily be discovered without the tool due to time constraints.

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