Simulation Modelling as a Decision Support Tool for Efficient Healthcare Layout Design

Irinie Roufaeel, Grant Mills, Anne Symons, Duncan Wilson, Paul Webster and Alan Penn
University College London, UK
Irinie.roufaeel.19@ucl.ac.uk

Abstract. We need to rethink the healthcare design and innovation process and particularly the evidence-base that drives it. Typically design techniques and guidelines do not involve simulation modelling, and rarely can we show how an optimum layout has been achieved. There have been previous attempts, but these have often focused on hard objective measures, which have not encouraged action and collaborative research. This paper proposes a hybrid and action-based simulation model that drives innovation in design.

1. Introduction

Healthcare design requires interdisciplinary collaboration and evidence-based techniques to achieve innovative solutions. Simulation modeling can help understand the complexity of the healthcare system, but an iterative hybrid simulation modeling framework is necessary to ensure success. This paper proposes an action research-based hybrid simulation model to achieve optimal outcomes through interdisciplinary collaboration. In doing so, it advances approaches to modelling and explores innovation in evidence-based and collaborative healthcare design (Hyrkäs et al., 2020; Nahhas et al., 2017; Stefanini et al., 2021; Hall et al., 2019; Caixeta & Fabricio, 2013; Halawa et al., 2020). Hall et al., (2019) for example highlighted the importance of academic collaboration to deliver innovative practice-based healthcare design emergence.

Three key issues are motivating the need for innovation in efficient healthcare design: patient demand is increasing at a rate higher than the capacity of the facilities available; staff overload and the need for improving working conditions; and third, rising costs related to poor design decision making which lead to poor outcomes. To address these, Architects must find dynamic ways to incorporate evidence and way to fit designs to operational processes and clinical (staff and patient) flows. Some have proposed the need for co-creating new collaborative models. For example,

This article considers how dynamic briefing and creative dialogues, agile approaches and physical prototyping have encouraged an interdisciplinary perspective within a specific design case study. It explains how an engaged process was created that allowed for the rapid testing of assumptions and enabled more effective design judgements between specialist designers, and those less able to express why something works (or not).

2. Healthcare facility design

A healthcare facility needs to provide urgency and speediness of patient treatment in a convenient environment (Aaronson et al., 2017). The physical layout of a facility plays a key role in either increasing or decreasing the efficiency rates and the productivity rate of a facility (Abo-Hamad & Arisha 2014). It is well known that there is an interplay between various sources of evidence that must be integrated in facility design, for example “healthcare facility design is a complex process that not only creates and allocates physical spaces, but also shapes the dynamic flows of patients, staff, visitors, equipment, and information." (Halawa et al., 2020). Figure 1 shows studies on the measured effect of physical layout on healthcare outcomes.

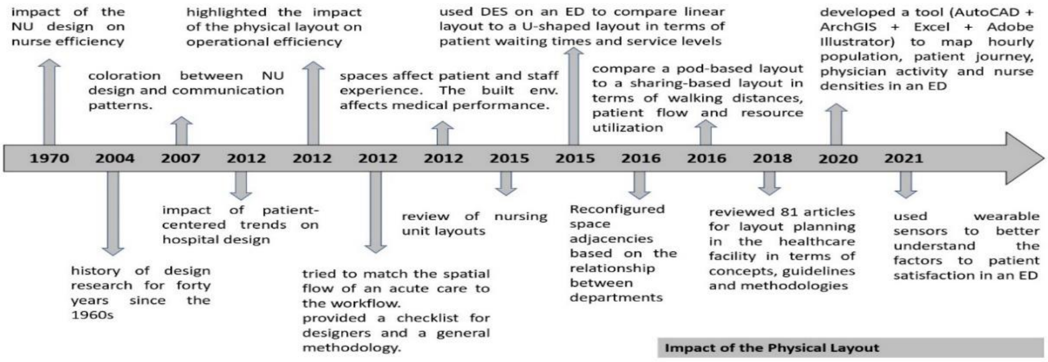

Figure 1: A Summary of the literature on layout-design in healthcare facilities up to 2018 (original)

Research has shown first that buildings can have a significant and physical impact on healthcare outcomes (Becker, 2007), however there are fewer studies that have explored the potential of simulation modeling to improve healthcare layout design outcomes and subsequently, healthcare outcomes (Kim & Lee, 2010; Morgareidge et al., 2014; Choudhary et al., 2010). There are also other indirect impacts, for example nurse workload and burnout have been shown to be inversely correlated with patient satisfaction (Venugopal et al., 2013) and efficiency (Kisliakovskii et al., 2017) and so we must find ways to simulate and support the effectiveness of layout design decision making.

While evidence-based design and simulation modeling have the potential to be a powerful tool for improving healthcare design, there are still limitations that need to be addressed, including lack of engagement of all partners, differences in objectives and priorities, and lack of a common understanding (Zych et al., 2020). What is more, given the complexity of healthcare facilities design, a collaborative approach if often necessary. Design processes will therefore involve architects, hospital managers, and other stakeholders who together can achieve optimal healthcare outcomes (Kohler, Gramazio, & Willmann, 2015; Hyrkäs et al., 2020). Rashid (2015) proposes the combination of evidence-based design and simulation modelling in the production of design guidelines. Playing a role in testing theories, resolving functional and spatial issues, testing layouts against a set of clinical objectives.

3. Simulation modelling and assessing facility efficiency

Evidence-based design and simulation modelling have immense potential if combined throughout the design process in an action research setting. Simulation modelling was first used by data scientist to conduct sophisticated mathematical modelling (Mohiuddin et al., 2017), but greater potential was found when it was used to help visualise the effect of different decisions on the overall efficiency of the healthcare facility, rather than reaching a mathematical optimum. Visualising a real-life case scenario, or providing common grounds for communication between different disciplines and people from different professions and backgrounds. For example, simulation modelling has been used in solving overcrowding problems where bottlenecks are detected, and smoother flow is acquired. According to (Clarke, Peavey, & watkins, 2013) simulation modelling was used to test the validity of design assumptions and innovative solutions. The challenge is to feed the simulation model with viable data that represents real-life case scenarios. A major part of finding a better solution is to firstly understand the system and understand how the system works. This helps in identifying the problem and come-up with better solutions such as patient flow modelling to improve overall healthcare performance (Shepley & Watson, 2013). Figure 2 shows the evolution of discrete-event simulation modelling from the experimentational phase in the 2000s to the application of wearable sensors to better understand the effect of layout design on patient satisfaction in 2021.

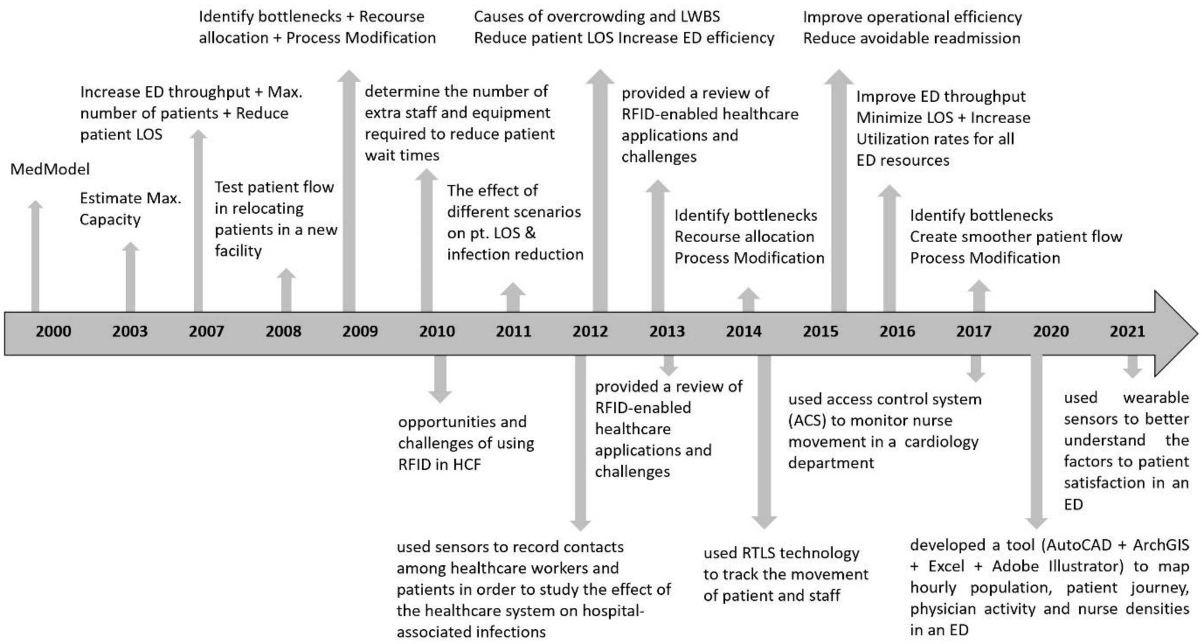

Figure 2: Timeline of literature on discrete-event simulation and sensors (original)

There has been an evolution in simulation modelling from hard modelling to soft-systems modelling. Although, its impact on architecture and healthcare facility design has up until now been marginal. Figure 3 illustrates the evolution of discrete event simulation (DES) modelling in the healthcare industry and highlights the importance in developing a new hybrid approach.

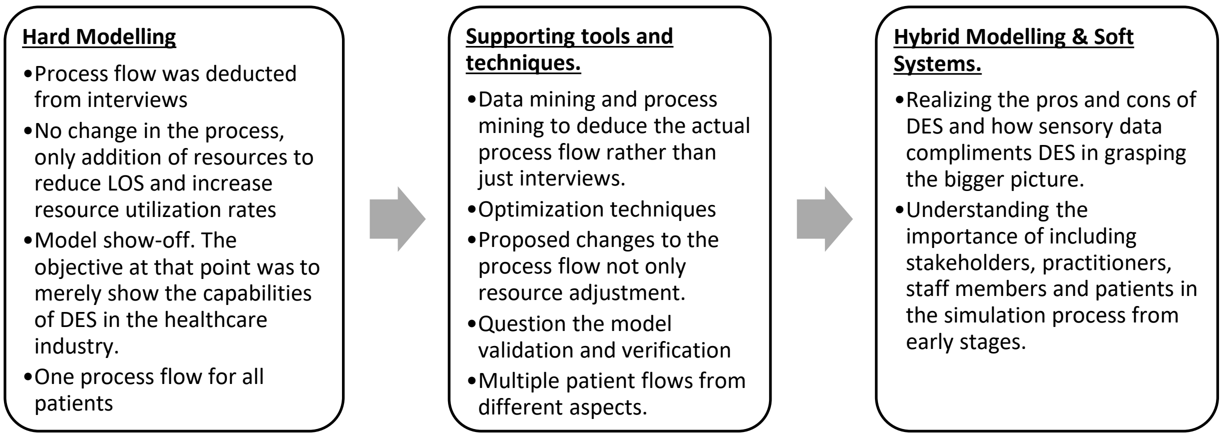

Figure 3: Discrete-Event Simulation Modelling Evolution in the healthcare industry (original).

4. Sensor use to validate simulation models

Previously, sensory data has been used with simulation. Table 1 provides a summary of the literature on wearable sensors and what role sensors have played in healthcare design. They show for example RFID use on healthcare case studies. While Yao et al., (2010) & Fosso

Wamba et al., (2013) set out some of the opportunities and challenges, this technology remains in its infancy in healthcare applications.

Table 1: A Literature Summary of Applying Sensors on Patient and Staff in the Healthcare Facility.

	Opportunities and Challenges	**Infection Control**	**Optimum Location of Sensors**	**Track Patient & Staff**	**Nurse Movement**	**Patient Satisfaction**	**Measure Walking Distances**
(Heo, Yeonsook; Choudhary, Ruchi; Bafna, Sonit; Hendrich, Ann; Kaiser, 2009)					X		
(Yao et al., 2010)	X						
(Wong et al., 2011)		X					
(Hornbeck et al., 2012)		X					
(Fosso Wamba et al., 2013)	X						
(Gharaveis et al., 2018)							X
(Singh et al., 2014)			X				
(Morgareidge et al., 2014)				X			
(Kisliakovskii et al., 2017)					X		
(Grzywinski et al., 2020)				X			
(Stefanini et al., 2021)						X	

This shows that there are various uses for data gathered from RFIDs. For example, Hornbeck et al., (2012) used sensors to record contacts among healthcare workers and patients and the implications on hospital-associated infections. The author's concluded that workers increase infection spread when they do not wash their hands. Others have used wearable sensors on patient and staff (Kisliakovskii et al., 2017, Morgareidge et al., 2014 and Stefanini et al., 2021), but it can remain unclear how design collaboration occurred between different parties (Mohiuddin et al., 2017).

Sensory data can be used to validate and verify the accuracy of the simulation models. Specifically, the effect of layout design on the overall efficiency of the system. RFID sensors can record the effect of layout on human behaviour, although the quality of a model is based on the quality of the data gathered to operate the model (Abo-Hamad & Arisha, 2014 and Arisha & Rashwan, 2016). Although the simulation modelling has deeply changed the industrial sector, its impact on architecture and healthcare has up to now been marginal. It has not been yet fully developed (Kohler, Gramazio, & Willmann, 2015). The challenge is to translate the data from the wearable sensors to valuable information that would be translated to design guidelines for future projects.

5. Case Study Methodology

Moorfields Eye Hospital is facing the challenge of reducing backlog due to Covid-19. Patient conditions have been deteriorated and there is a risk of the increase in number of deteriorated cases because of the delay in diagnostics and treatment. The challenge faced in this project is the provision of an innovative diagnostics hub in a shopping centre. Ophthalmology, the busiest NHS outpatient specialty (7.9 million episodes; 2018-19), is perfectly suited to providing a testbed for rapid, research-driven innovation and to show how research in the built environment can better inform clinical and technological advancement.

This is a clinically led project where the design is defined by the patient and staff process flow of diagnostic tests. Physicians, engineers from different disciplines and modelling experts have worked in an interdisciplinary manner to reach a holistic optimum where efficiency means patient satisfaction, staff efficiency, maximum utilization rates of diagnostic equipment and minimal costs. This is a clinically led case study with the involvement of a team of designers, engineers, and expertise in the built environment.

Patients were categorized into two cases: medical retina patients (MR) and glaucoma patients (GL). They self-check-in then wait for a technician to assist them through the entire process till exit point. This can be seen in Figure 2.

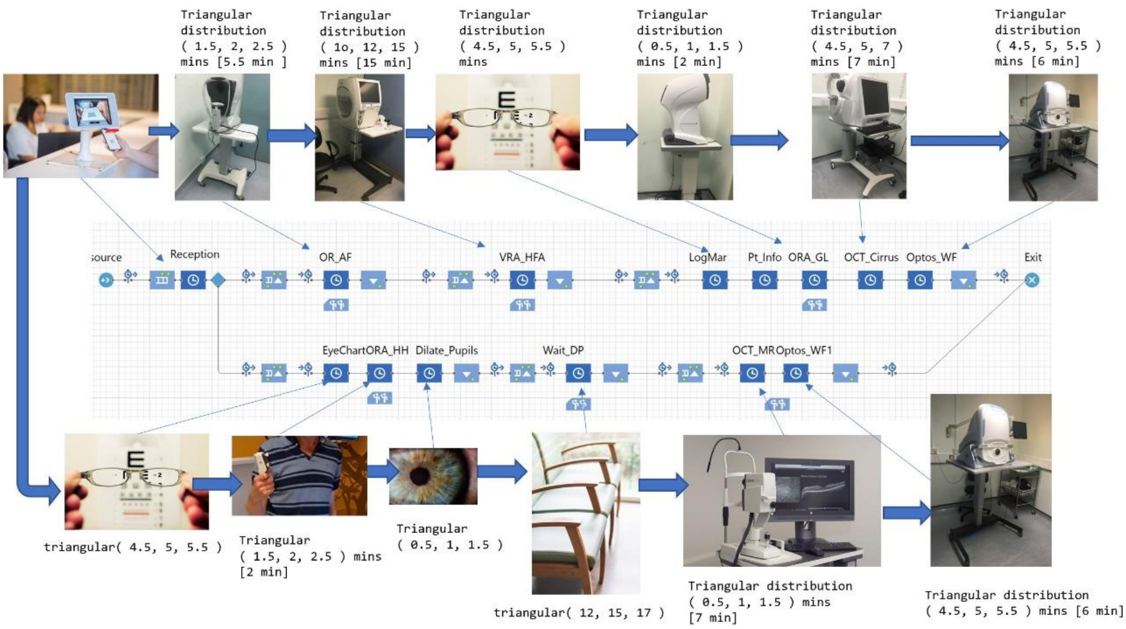

Figure 2: Clinical Process Flow for GL and MR patients

It was important to solve the bottlenecks that resulted from placement of lanes, pods and equipment pools and so different modelling approaches will be applied. Modelling was used to demonstrate the effects of different layouts, adding in considerations for discussions with the technicians (e.g., adding a bathroom to reduce patient time). This can be seen in Figure 3.

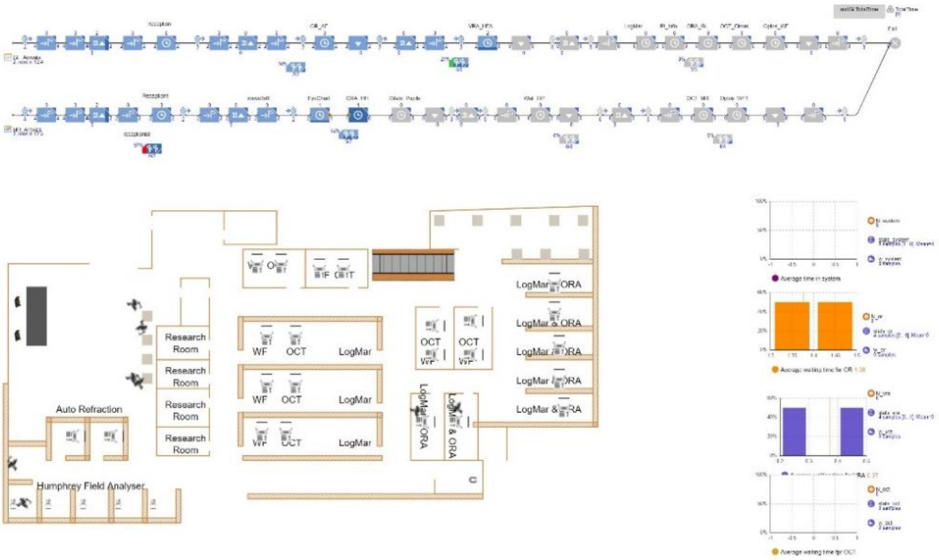

Figure 3: Simulation model using Anylogic Software

Figure 4 shows an indicative simulation model used to illustrate the clinical flow and used to facilitate a discussion on efficiency and smooth running with no bottlenecks. It was also used to make sure that there are no patients in the system after the official working hours for the technical team. An iterative approach was used to alter the simulation model and the layout setting.

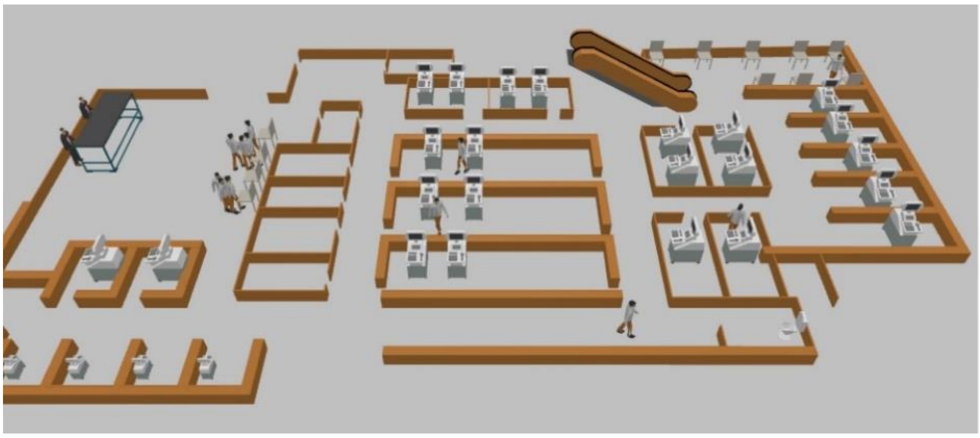

Figure 4: 3D simulation run for iteration one

6. Results

A comparative analysis between the simulated data and the Ubisense data was conducted for both patient types, medical retina patients and Glaucoma patients. The left-hand side of Figure 5 represents the comparison for medical retina patients while the right-hand side represents the Glaucoma patients. The clinical pathway for each patient type was divided into three main/grouped activities where several machines/tests are grouped in one pod: Vision, Dialation, MR for the Medical retina patients. And AF, HFA, GL for the Glaucoma patients. The orange bars represent simulated results while the blue bars represent the Ubisense data.

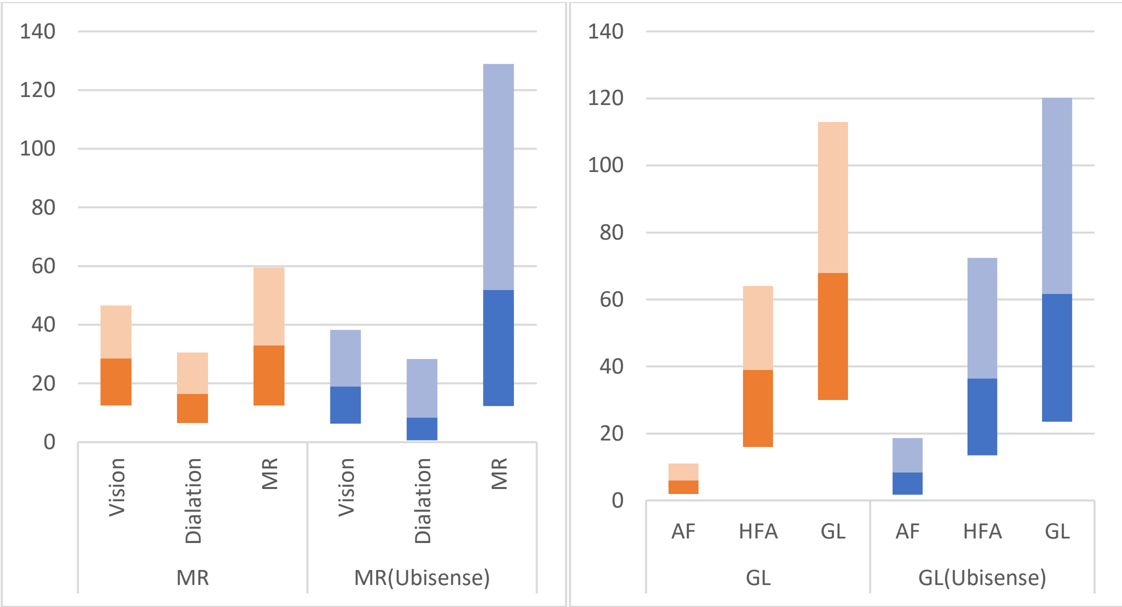

Figure 5: Comparative analysis between Simulated duration and actual duration for both patient types

It was found that there is a discrepancy in total patient times in the system. So, a workshop was conducted with the technicians to understand the reason behind the difference of activity durations and total journey time of patients. behind this discrepancy in results. It was found that the HFA machines for the Medical Retina patients needs recalibration due to its exposure to high levels of light. And in terms of the Glaucoma patients, a journey to the toilet was a necessity since the patients are all elderly patients and the bathrooms were located outside the diagnostic hub. It was a 15 min journey.

7. Conclusion and recommendations

The combination of sensory data and simulations played a vital role in better understanding the effect of layout design on overall performance of the healthcare facility. It helped validate and create a shared model of our environment that better represents the real-world problem.

The challenge is always to design a physical layout that harmonizes with the process flow, while ensuring patient and staff satisfaction and maximizing utilization rates. However, outdated standards, lack of evidence-based design guidelines, and absence of lessons learned from previous experiences hinder the process. A framework is needed to achieve guidelines and a holistic approach to the system. A hybrid simulation modelling approach is proposed that is deployed in an action-research setting to improve design outcomes and healthcare outcomes. This will facilitate communication between architects and hospital managers/stakeholders, leading to an efficient flow, solving backlogs, and overcrowding, and reducing medical errors.

The next steps in this research are to test the proposed framework and apply it to other case studies of different complexities. The potential of hybrid simulation modelling will be shown as a catalyst for delivering a physical layout in harmony with the clinical process is significant. This will involve as well testing the interaction between the real and virtual, simulation modelling techniques using advanced sensors and cameras. Ultra-wideband real-time location system (RTLS) (Ubisense, 2022). These sensors can gather behavioral information on how the medical staff and patients navigate and interact in a physical space and help verify the simulation model in terms of its capabilities in mimicking the real-world scenario.

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