# P1128

# A review of different approaches to access and people circulation within health-care facilities and the application of modelling, simulation and visualisation

M. Nazarian, A.D.F. Price and P. Demian
*Loughborough University*

**Abstract:** Evidence suggests that improving access and people circulation in hospitals can: improve staff performance and productivity; enhance patients' safety, privacy and rate of recovery; minimise the risk of cross-infection; reduce the delay time of external service delivery; create a more welcoming environment for visitors; and reduce the evacuation time in emergency situations. Consequently the need to design hospital layouts that benefit from the most effective system cannot be over-emphasised. This paper focuses on identifying different systems of access and people circulation in health-care facilities in general and hospitals in particular. The research on access and people circulation reported in this paper comprises three main phases. The first phase involves a literature review of existing health-care environments to identify different types of access and people circulation requirements. The second phase focuses on categorising the adopted approaches and systems in order to compare and contrast the advantages and disadvantages of each. The final phase provides a critique of current modelling and simulation tools being applied during the planning and design phases to improve access and people circulation. The paper concludes with recommendations, which will be used to shape future research in the area.

**Key words:** Accessibility, Circulation, Layout Design, Hospital, Healthcare, Simulation, Modelling

## 1. INTRODUCTION

Research has linked the quality of care, patient health and wellbeing with the physical attributes of the healthcare environment (e.g. Gesler et al, 2004). It is understandable that supportive built environments with good internal layouts, accessibility, and circulation can create an overall inviting, calming, engaging, and more hygienic and productive healthcare environment for staff, patients and their relatives.

Design of a healthcare unit influences the patients' quality of care in many ways. One of the known effects of the hospital layout on care quality is the amount of wasted time because of the unnecessary journeys by the staff. Some studies have investigated the impact of the unit layout on the amount of time spent walking (e.g. Shepley, 2002; Shepley and Davies, 2003; Sturdavant, 1960; Trites et al, 1970). They demonstrated that time saved walking was translated into more time spent on patient-care activities and interaction with family members in several studies.

Being an automotive industrialist, Henry Ford was one of the first to notice the inefficiency of former hospital designs in meeting their purpose and said that "in a normal hospital, nurses are forced to make many unnecessary steps. Hence they spend more time walking around than nursing the patients". He then laid out his employees' hospital in such a way as to avoid 'superfluous steps' (Kuhn, 2000).

This seems to still be a challenge, even now, in the 21st century. According to Dillani (2010) caregivers spend 49% of their time in corridors. Considering the time they spend in other spaces (e.g. nurse station16%, patient rooms 19% and other rooms 16%), this emphasises the importance of layout design in enabling caregivers to release time for patient care.

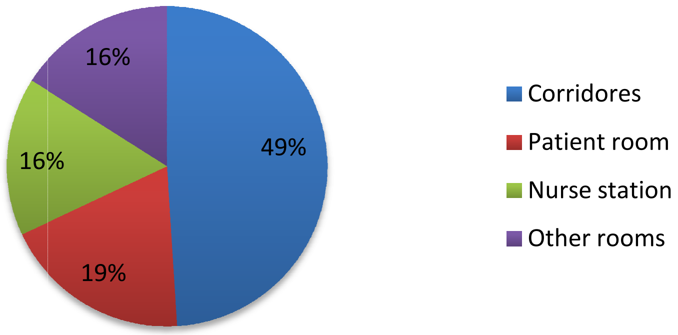



*Figure 1. How caregivers spend their time. Source: Dilani (2010)*

Other than staff's walking distances, many other aspects of healthcare quality can be affected by the layout design of the hospital. A good design is expected to improve staff performance and productivity; enhance patients' safety, privacy and rate of recovery; minimise the risk of cross-infection; reduce the delay time of external service delivery; create a more welcoming environment for visitors; and reduce the evacuation time in emergency situations. It is, therefore, correct to state that the design of a hospital impacts all its users, including patients (inpatients and outpatients), hospital staff (nurses, doctors, managers, etc.), visitors and others. Among these groups, nurses are considered to be the users who spend the most time providing direct care to the patients; therefore, it is natural to give their needs the higher priority when designing a hospital.

This paper studies the effects of different designs on the efficiency of the nursing staff. The first step was to identify the different types of hospital layout design. This shaped the basis of the selection of layout types in regards to access and circulation systems, however, hospitals are normally large buildings and this means that deciding on the scale of the study of design types is also very important. The reason is that if a hospital is studied in its whole, the study will be limited to the general and overall layout of the building and its circulation systems. This will lead to overlooking the many issues that may exist in smaller scales inside the units. On the other hand, a too focused study, which deals with individual spaces, could mean ignoring important aspects such as adjacencies and people flow.

It is, thus, a reasonable choice to focus the study on a more intermediate scale to allow for conclusions that will cover the biggest part of the circulation issues. The ward seems to be a more appropriate scale here, because apart from being from that intermediate scale, it also accommodates most of the active time of the nurses and hosts the biggest percentage of the users of a hospital, meaning inpatients (MAPS, 2010).

For this reason, this paper will focus on:

- introducing a method for identifying different trends in designing wards; and
- reviewing available computer-aided simulation tools for comparing different ward design types.

## 2. APPROACHES TOWARDS HOSPITAL WARD DESIGN

Ward design can be studied from different points of view (e.g. size, function, environmental factors, aesthetics and psychological factors, safety, etc.). The ward layouts discussed in this section are categorised based on the system of access and circulation inside them; therefore, it is the circulation system and the way that ward spaces (patient space, nurses' base and staff space) are arranged around the circulation system that formulates the type of ward layout in this paper.

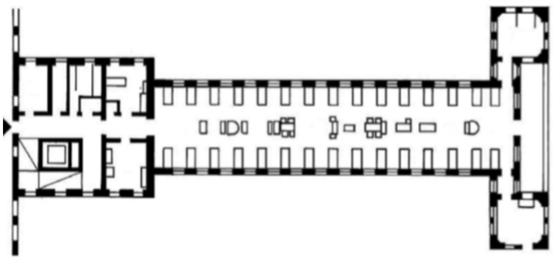
Patient space may contain single-bed rooms, multi-bed rooms or both. In Scandinavia the preference is for single-bed rooms, in USA for two-bed rooms and in the UK until recently for 4 to 6-bed bays. New UK research advise that 50% to 100% of all patient rooms should be single occupancy in newly built hospitals (Dowdeswell et al, 2004) to provide for patients' privacy and cross-infection control. However, the provision of single-bed rooms and multi-bed bays is the subject of a wide debate. In addition, a day space is required in wards and a toilet and shower should be provided for each bay.

The nurses' base is a very important element in the ward's environment, as it should allow nurses to monitor the largest possible number of patients. Hence, it is recommended to be central in the ward to act as an organisational hub to the ward. On the other hand, the staff space contains nurses' room, doctors' room, treatment room, staff lounge, clean utility, dirty utility and other rooms which are usually used by staff.

The types of hospital wards can be classified according to the arrangement of these three spaces together and around corridors within the ward. James and Tatton-Brown (1986) classified wards into seven types. These types were: simple open or Nightingale form; corridor or continental form; duplex or Nuffield form for greater amenity for patient and staff; racetrack or double corridor form to achieve more compactness; courtyard form which achieves better natural ventilation; cruciform or cluster for better observation and finally the radial form to reduce staff travel distance (Alalouch et al, 2009). More recently, HBN 4 (1997) also provides a list of different hospital wards in UK from a management point of view as follows: Nightingale ward; Sub-divided ward (early 20th century and post war); Nuffield ward; Falkirk ward; and Nucleus ward.

In this study, a combination of these two classifications is used, in order to cover a more comprehensive variety of different ward layout designs. As a result, five different hospital wards are introduced based on a geometrical rearrangement of the classifications given by James and Tatton-Brown (1986) and NHS Health Building Note 4 (1997). Five examples are also presented, in order to investigate the practical application of the ideas of each layout type.

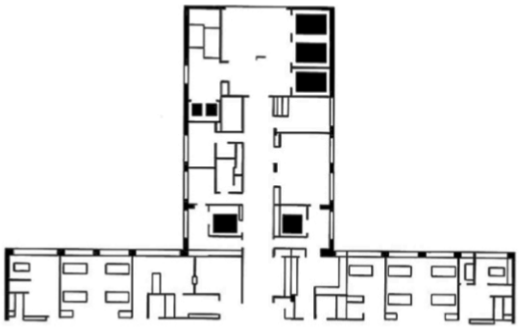
### 2.1 Corridor ward



*pe, St Thomas hospital, n-Brown (1986)*

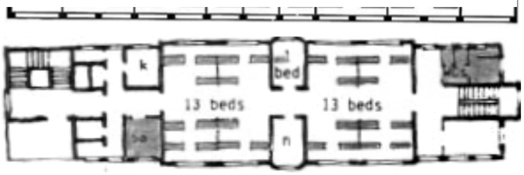
The Corridor ward is, in essence, the developed form of a historical form of ward known as Nightingale ward. The Nightingale ward or Long-nave ward (as called by HBN 04, 1997) was a type of hospital ward, which contained one large room without subdivisions for patient occupancy (Pattison et al. 1996). It was developed at the end of 1870s and was named after Florence Nightingale. It might have side rooms for utilities and perhaps one or two side rooms that could be used for patient occupancy when patient isolation or patient privacy was important (Pattison et al. 1996). According to Pattison, Nightingale wards contained open bed base for approximately 30 beds usually arranged along the sides of the ward. According to HBN 04, men and women were cared for in separate wards.

This design was later improved to what we today know as Corridor ward (or Continental ward) due to new concepts in reducing cross infections in hospitals as well as patients' privacy and dignity (Pattison et al, 1996). To consider these concerns, in the Corridor design, patients are located on one or both sides of a corridor with four to six beds per room. The corridor design may be in a "T," "C," or "L" shape" (Catrambone et al, 2008).



, London, source: James

In an early 20th century variation of Corridor ward, known by HBN 04 (1997) as "Sub-divided ward", the nursing station and a single room split the ward in two. The overall management and clinical supervision in this model were to a large extent similar to those of Nightingale wards with the difference that subdivided ward allowed men and women to be cared for in separate wings of the same ward (HBN 04,1997).



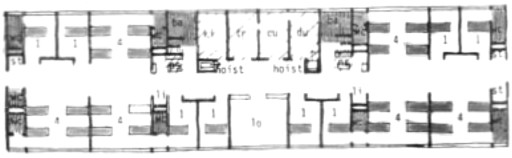

bdivided ward type, early
)4 (1997)

Nucleus or deep plan ward is another variation of Corridor ward design, which originally belongs to 1980-1990s when the oil crisis of the mid 1970s recognised energy demands of deep planned buildings. Under this design, "Florence Nightingale's original concept of hospitals with fresh air, light, and views was replaced by deep plan hospitals that prioritised efficiency over human comfort and healing" (Burpee, 2008)

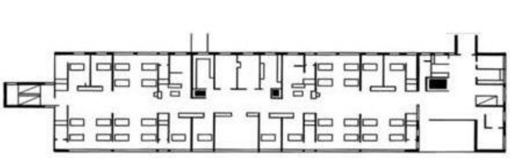
The layout has a modular concept design, based on reducing energy consumption, maximising external wall area available for windows and reducing number of floors. Support facilities are located in the centre. The en-suite facility is provided in the case of a single room (HBN 04, 1997).

## 2.2 Duplex ward

This type of ward belongs to the 1950s. The Duplex configuration (also known as Nuffield) is, in fact, a combination of two Corridor wards, each including its own station, but sharing support space that is located between the two wards (Catrambone et al., 2008). The beds continued to be in small groups each with its own sanitary area, but the growing awareness of the problems of cross infection - coupled with the desire to avoid disturbance to other patients - introduced a special room on each ward for carrying out clinical procedures and treatments (Smith, 1966).



e, 1950s, source: HBN 04



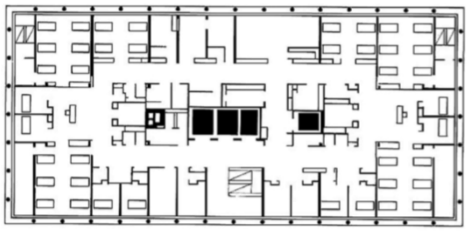
)lex ward type, Larkfield
ames and Tatton-Brown

"The single nursing team largely remained, but on a day-to-day basis the team was split to cover separate areas of the ward. By this time, patients of several consultants might be accommodated in one ward.

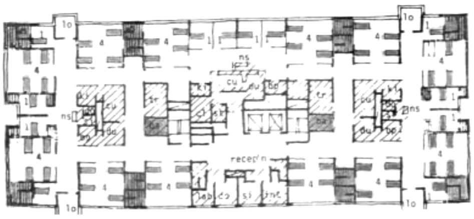
Sometimes, the wings were used to accommodate the patients of different consultants or patients of different genders" (HBN 04, 1997).

## 2.3 Racetrack ward

Post-war Racetrack appeared in 1950s-60s with provision of 16-60 beds in various mixes of patient dependency. "This ward layout provided a mixed-sex ward with multi-bed bays for use either by female or male patients" (HBN 04, 1997). The 'racetrack' ward had patients rooms arranged around a central core of services. Sisters desk was replaced by a nursing station, where staff could sit instead of being on their feet all day by their patients. Privacy was fine for those admitted for elective surgery, but when seriously ill the constant observation and presence of the nurses were more important (Rivett, 2008). The racetrack design (also known as double corridor) has nursing work and support spaces between two corridors. This is believed to be one of the most common designs in the US (Page and Page, 2004).



*ard type, High Wycombe shire, UK, source: James 86)*

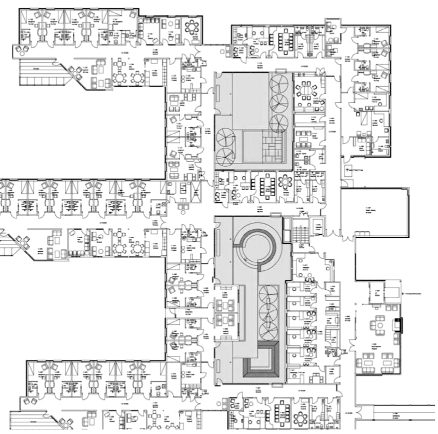


*k ward type, source: HBN*

A specific variation of Racetrack design was the Falkirk ward type that appeared in the 1960s (HBN 04, 1997). It has a core of facilities and dispersed work stations. Four bedded bays, which enjoy more generous bed space standards with internal glazed partitions, are one of the characteristics of this ward type.

An obvious shortfall of Racetrack ward type was its long corridors with no natural light and view. Barefoot (1992) stated that: "the racetrack ward is a failure; one should avoid too long corridors without windows. The reassurance of relating to outside orientation is vital. It can be done with corridor breaks giving pleasant views of the outside." One of the most commonly used solutions to this shortfall was the introduction of Courtyard wards.

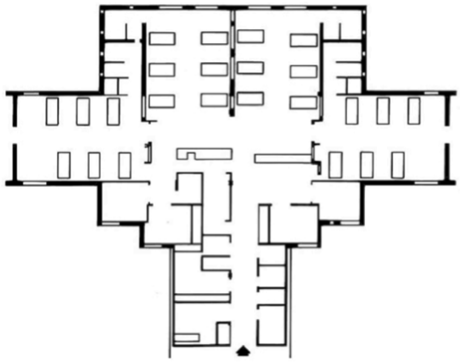
According to Catrambone et al (2008) the courtyard ward is another variation of racetrack design with courtyard for ventilation in the middle of the building. In this type of plan, courtyards of varying sizes are inserted into the core areas to provide natural light and ventilation.



*rd ward type, Acute nt, Norway, Source: Plan 005)*

## 2.4 Cluster ward

In this type of ward design, the geometry works as a generator. "The combination of orthogonal and diagonal axes can generate close packing plan forms for single room layouts" (HBN 4 Volume 2). "Geometric designs are used to gain more external wall area so that the use of natural light and ventilation can be increased. They also provide solution to deal with deep plans and internal corners



which commonly produce “dead” space, which cannot be used for continuous nursing activity” (HBN 4 Volume 2).

The most common form for cluster ward is cruciform, which is a modification of the corridor plan to ensure that as many patients as possible are gathered around the nursing station while providing privacy enhancements such as walls and doors (Catrambone et al, 2008).

*cluster ward type, Weston*
*, source: James and Tatton-*

## 2.5 Radial ward

*ancis Xavier Cabrini*
*Canada. Source: HBN*

A study by a group of researchers lead by Catrambone (2008) found that, in general, a radial ward design was the most desirable (related to single and double corridor designs), both in terms of saving unnecessary ward travel and of increasing time with patients. Moreover, members of the nursing staff indicated a preference for assignment to the radial ward. The fact that nursing staff in the radial unit had more free time was interpreted as an indication that more patients could be housed on the ward. The radial design is a circle that permits a “fishbowl” view of each room from the nurses’ station (Catrambone et al, 2008).

In this part, a review of five most common ward design approaches in the last 150 years was presented. Their known points of strength and weakness as stated in the literature review were discussed and examples of each design were studied. The following sections will present a discussion on the tools available for a quantitative comparison between the quality of access and circulation in these types.

# 3. MODELLING DIFFERENT WARD TYPES

Computer-aided simulations enable the researchers and designers to study numerous scenarios in a short span of time in order to reach to the optimum solution for a problem. On the other hand, relying on case studies for studies like this could make way to unwanted factors (such as case study’s size, staff numbers, workloads, environmental factors, etc) that may confound the results expected from the study. It could also leave a lasting doubt about the representativeness of the case studies because of mentioned inevitable differences.

To suggest a method for comparing different designs available for a general ward, a set of different designs for a hypothetical ward is needed. This will facilitate a comparative study on the system of access and circulation in different types.

To keep the characteristics of these generic forms more repeatable and simple and to avoid the complexities that might obstruct a more systematic comparative analysis of the geometry of the types, a number of simplifying and coordinating measures are needed to be equally applied to all different types. This is to keep as many characteristics of the different types as possible similar to each other and therefore leave the geometry and layout of the ward as their main comparable characteristic.

The first and most important factor that should be kept equal and identical in all different types is their size and consequently the number of the beds. Another very important factor is the function of the wards and the activities of the nursing staff within them.

These design types must cover the common ward styles (as discussed above) and the main factor differentiating between them needs to be limited to the design of access and circulation of the staff in them. In other words, the design types studied here should cover all the most common combinations of the spaces in a general ward.

By eliminating hospital wards that need special considerations (such as paediatrics, cardiothoracic surgery and trauma and orthopaedics), general medicine wards and wards with similar architectural needs (like general surgery and geriatric medicine) form the biggest majority of the wards in UK hospitals (Figure 13).

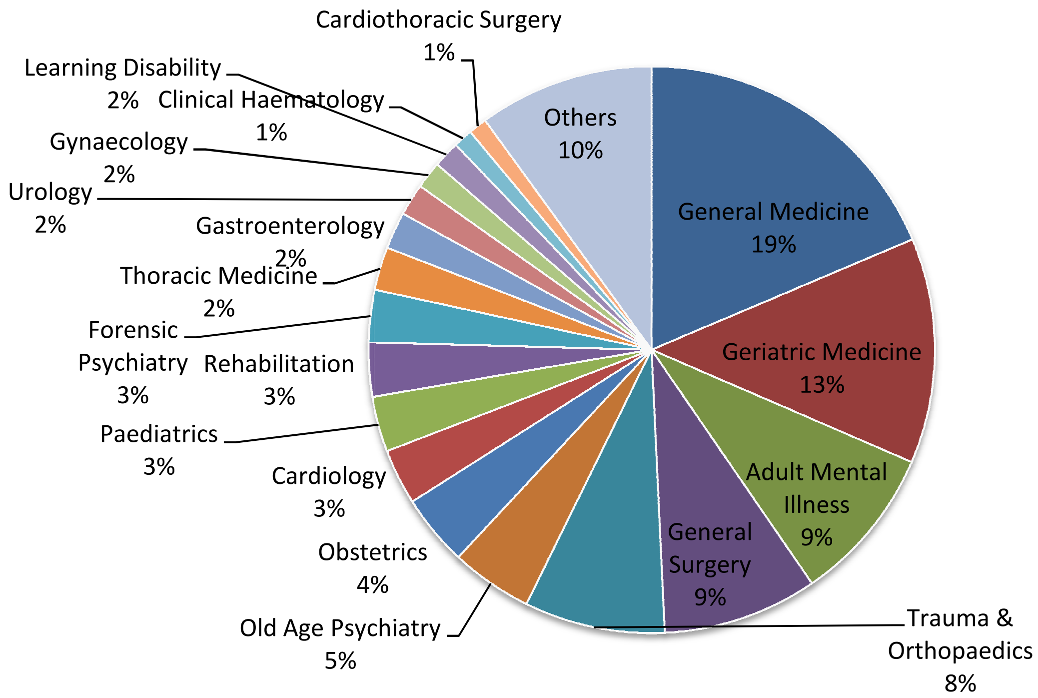



*Figure 7. Average number of occupied beds by ward-NHS England, Source: DH (2010)*

The Department of Health measures the average number of beds in a general ward at 18.6 beds (DH, 2010) and demands that a minimum of 50% of all beds in every ward need to be in single rooms (Dowdeswell et al, 2004). As a result, archetypal models of each ward type are designed to accommodate a total of 20 patients in 4 single rooms and 4 multi bed rooms. Configuration of ward spaces is decided based on the characteristics of each type. A geographical representation of the archetypal models is presented below (Figure 13).

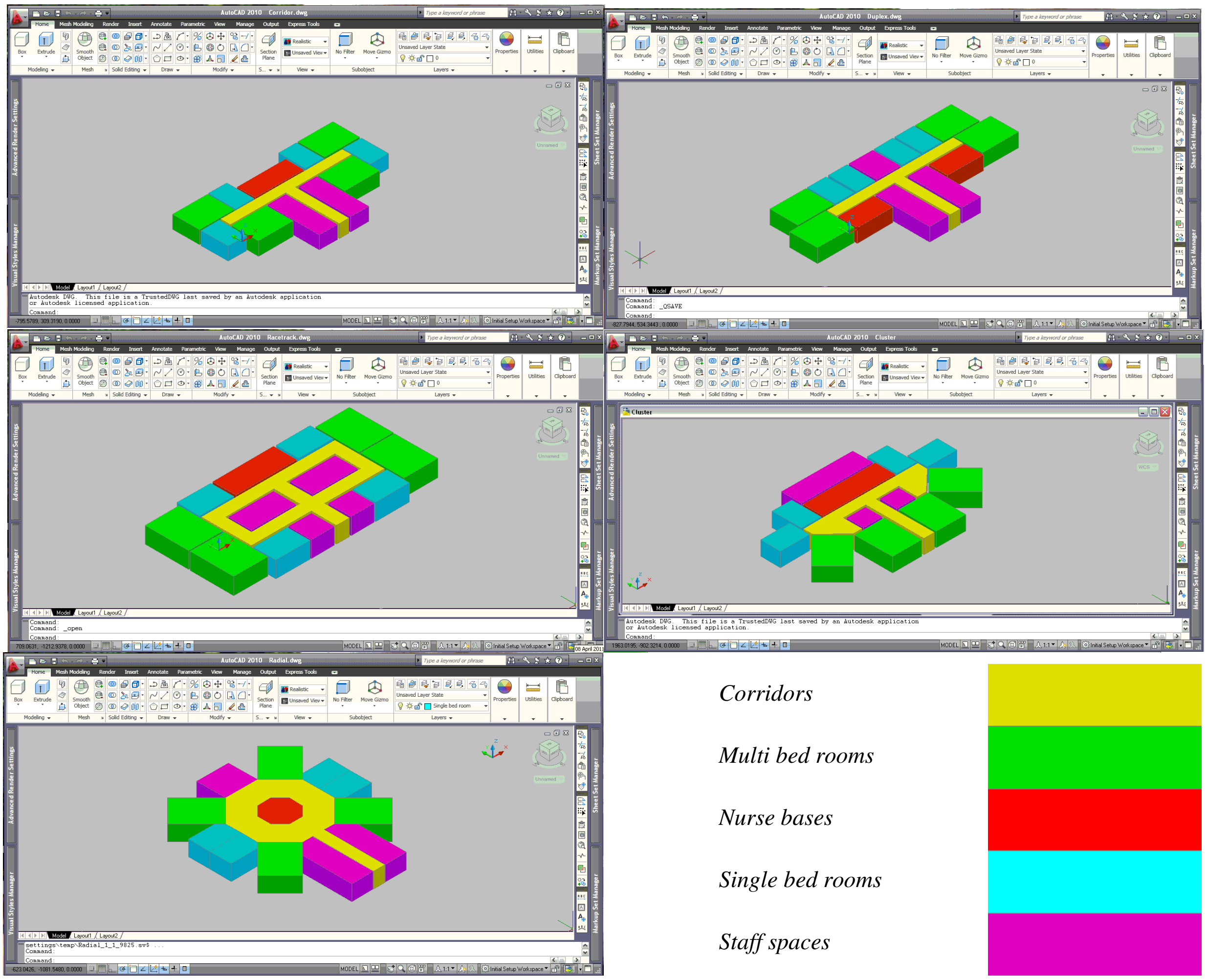



*Figure 8. Gometrical models of 5 types (1. Corridor, 2. Duplex, 3. Racetrack, 4. Cluster, 5. Radial)*

Apart from the geographic characteristics of different spaces in the ward, their technical specifications are also important. Activity DataBase (ADB) is the Department of Health's briefing and design tool used to develop healthcare environments, which provides such technical specifications. ADB provides room data sheets and graphical room layouts, produced from Department of Health (DH) datasets - derived from Health Building Notes (HBNs) and Health Technical Memoranda (HTMs), and reflecting DH baseline standards. It has been estimated that ADB is used on over 90% of healthcare construction projects in the UK (DH, 2007). A combination of geographical and technical characteristics of each type provides enough information to build its model in any simulation program. The following is a review of some of the simulation tools available for this task.

## 3.1 A review of available simulation tools

Healthcare planners and designers have traditionally used best practice standards to guide organisation of spaces and provide appropriate facilities in a healthcare unit (Choudhary et al., 2009). However, recent developments in simulation and modelling techniques have promised a more dynamic alternative, wherein the healthcare delivery process can be modelled to compute appropriate amount of facilities required for different types of healthcare processes and analyse patient flows (Eldabi et al. 2007, Gibson 2007). The modelling, simulation and visualisation in the design of healthcare facilities in general, and in assessing their accessibility and circulation systems in particular, can facilitate:

- comparing, evaluating and examining numerous different design approaches within minimum time and budget; and
- exchange of visualised design ideas between designers, clients and contractors

People circulation is the process that incorporates reception, security, access control, visitor announcement, parking, taxi and other functions and services normally used to manage the people circulation in the hospital.

In order to select the most appropriate tool for modelling and simulating the ward categories listed above (Figure 13), a series of actions were taken as the process of software selection. These actions included:

- First) A general review of 52 available modelling tools in the market, in order to find those more widely used in healthcare facility design and eliminate those less relevant to the requirements of the research.
- Second) Comparing the details of the characteristics of the remaining seven tools (AnyLogic, Arena, Flexsim HC, MedModel, Simcad, Simio and Simul8) to find those most appropriate for this research. These seven programs are briefly introduced here:

### 3.1.1 Anylogic

AnyLogic is a dynamic simulation tool that supports all conventional approaches of simulation methodology; system dynamics, process-oriented (discrete event) and agent-based modelling. These methodologies can be mixed in one model.

This software enables the user to represent many corporate application fields, such as production, logistics, business processes, market and competition, or supply chain.

### 3.1.2 Arena

Arena is a simulation program designed for quick and low-cost animations in 2D with the potential for more detailed 3D post-animation processing. It has a design optimisation capability (based on OptQuest) that together with the possibility of automated input analysis (integrated within the software) and its ability to adapt with Visual Basic programming language, make Arena one of the easier-to-use options in the market. Special versions have been designed for modeling factories, call centres, packaging lines and flow processes.

### 3.1.3 Flexsim

Flexsim is a tool for modelling, analysing, visualising and optimising processes in different fields. Regarding shapes and layout issues, Flexsim is able to add realism to the model by using custom 3D shapes of the buildings, machines, or products. Then it will import 2D or 3D CAD drawings to use as a floor plan or topographical layout. It is also interfaces with other programs and programming languages, such as C++, Access and Excel. Different specialised applications have been developed for Flexsim to make it easier for using with different scenarios. Among them is Flexsim HC, which is specifically designed for modelling different healthcare scenarios.

### 3.1.4 MedModel

MedModel is a specialised version of the simulation tool, ProModel, designed for visualising, analysing, and optimising the performance of healthcare systems. It is a predictive analytic tool, based on discrete event simulation, designed specifically for the healthcare industry to evaluate, plan, and design/redesign the processes, procedures and policies of hospitals, clinics and labs. MedModel models can be used to identify inefficiencies in an existing process and test a variety of scenarios. The animation and graphic output results show the behaviour of the system under any set of circumstances. Its realistic animation capabilities and the potential to be used in link with Visual Basic language makes performing simulations easier for non-professionals.

### 3.1.5 Simcad

Simcad is a dynamic process simulator with a built-in dynamic optimizer tool and integrated work order/schedule optimization. It allows experimental designs in a dynamic interaction in a model or through integrated optimization. It can also publish simulation results to an integrated tool called Simcad Scenario Analysis.

### 3.1.6 Simio

Simio is a Discrete-Event simulation software with automated scenario management and the ability to analgise the result of simulation as summery statistics or animations that can be exported to in different formats. Although it offers a good modelling speed and flexibility of process it still does not include solutions for design optimization. Simio is designed to simplify model building by promoting a model-ing paradigm shift from the process orientation to an object orientation (Rossetti et al, 2009)

### 3.1.7 Simul8

Simul8 is a relatively easy-to-use tool, representing the simulation in a realistic 3D environment with the ability to model in 2D and 3D and produce Virtual Reality animations. Simul8 can be integrated with C++, Access, VB and Excel to make the transfer of input and output data easier. Another helpful potential of the software is its ability to optimise designs through: cost reduction, efficiency maximisation, future performance improvement and guesswork illumination.

- Third) Further investigation with the aim of choosing the most appropriate program revealed capabilities and limitations of each of the seven tools. These have been summarised in the following table (Table 1).

As shown in the table, all of the shortlisted programs meet most of the requirements of the study. However, minor shortfalls in some of them lead to their elimination in the selection process. Since the ability to export animations, the potential of seeking online help from other users and optimisation capability are among important factors expected from the software to be used in this research, the last three programs in the table (i.e. Simcad, Simio and Simul8) are not considered the most obvious choices here. MedModel data export is also mainly based on text format. Animation export, however, is not impossible if suitable secondary programs are used. On the other hand, MedModel together with Flexsim HC are the only two programs in the list that are specifically made

*Table 1* Comparing capabilities and limitations of shortlisted programs

| | | | Model Building | | | | | | | | | | Animation | | | | Support/Training | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Software | Typical Applications of the software | Primary Markets for which the software is applied | Output Analysis Support | (Specify) | Batch run or experimental design | (Specify) | Optimization | (Specify) | Code reuse (e.g., objects, templates) | Model Packaging (e.g., can completed model be shared with others who might lack the software to develop their own model?) | Cost Allocation/Costing | Mixed Discrete/Continuous Modelling (Levels, Flows, etc.) | Animation | Export animation (e.g., MPEG version that can run independent of simulation for presentation) | 3D Ani-mation | Import CAD drawings | User Support/Hotline | User group or discussion area | Training Courses/Consulting |
| **AnyLogic** | Flexible general purpose simulation tool. Discrete Event, Agent Based and System Dynamics modeling | Healthcare, Logistics, Supply Chains, Manufacturing, Defense, IT, Pharmaceuticals, Marketing, Finance, Energy, Education | y | Dataset Statistics, Distributions, Regular and 2D Histograms, various Charts, etc. | y | Simulation, Optimization, Parameter Variation, Compare Runs, Monte Carlo, Sensitivity Analysis, Calibration, Custom experiment | y | OptQuest | y | y | y | y | y | y | y | y | y | y | y |
| **Arena Simulation Software** | A proven and easy to use general purpose DES software tool. The only boundaries are in the ability to describe the process. | Manufacturing, Six-Sigma, Packaging, Supply Chain/Logistics, Healthcare, Military/Defense, Service, Contact Centers, etc. | y | Output Analyzer tool, Summary Results, Ability to export data to other sources. | y | Scenarios can be defined to experiment on parameters. | y | Optquest | y | y | y | y | y | y | y | y | y | y | y |
| **Flexsim HC** | Hospital ER and related healthcare/patient flow applications | Healthcare, emergency rooms, patient flow, patient services, lab, staff balancing | y | Flexsim Charts, Flexsim Dashboards | y | Flexsim HC DOE | y | OptQuest | y | y | y | y | y | y | y | y | y | y | y |
| **MedModel Optimization Suite** | Design, plan, evaluate and improve processes of hospitals, clinics, and other healthcare systems to optimize performance | Hospitals, Clinics, Healthcare Systems, Medical Device Manufacturing and Sales | y | Output analysis reports and charts included. Also outputs to Excel and Access for analysis. | y | Unlimited scenarios can be predefined to experiment on parameters | y | Optimization available using OptQuest and/or SimRunner | y | y | y | y | y | | y | y | y | y | y |
| **Simcad Pro-Patented Dynamic Process Simulator** | Continual Process Improvement, Facility Layout/Design, RFID/RTLS, Process Optimization, Lean, CapEx Justification | Healthcare Solutions | y | Value Stream Maps, Gantt Chart, Scenario Analysis, Lean Reports, | y | Integrated optimization. Monte Carlo batch runs | y | Built in Dynamic Optimizer Tool, On-the-fly user interaction, Integrated Work-Order/Schedule Optimization, | y | y | y | y | y | y | y | y | y | | y |
| **Simio** | manufacturing, healthcare, airports, military, ports, supply chain, warehouse, lean/six sigma | Healthcare | y | experimentation, confidence intervals, summary statistics | y | automated scenario management | | | y | y | | y | y | y | y | y | y | y | y |
| **SIMUL8 Professional** | Optimize throughput, business process management | Healthcare | y | Centralized results database, Scenario and run comparison, charting and reporting | y | Automated batch runs. Scenario Manager. Execute runs simultaneously across multiple PCs with parallel processing | y | Optquest | y | y | y | y | y | | y | y | y | y | y |

to simulate healthcare environments. This means that many of common spaces, equipment, agents' behaviour and procedures are already implemented in the software. For this reason, these two programs are kept in the shortlist of the high priority tools in the process.

Another software with a unique ability is AnyLogic. This ability is to integrate agent-based simulation in the process. Agent Based Simulation (ABS) is a method of simulation that considers the probability of the decisions made by different autonomous entities (agents) as a result of the existing conditions at each phase of the simulation. This contributes to the ability of simulation agents to learn and to optimise their behaviour within the simulation environment. This makes simulation results considerably more realistic in comparison to Systems Dynamic and Discrete Event Simulations.

Apart from AnyLogic, a network-based product of Flexsim family (Flexsim DS) is the only program in the initial list that covers agent-based simulation. But Flexsim DS, unlike Flexsim HC, is not specifically designed for simulating healthcare environments and, for this reason, is not included in the final shortlist.

Based on the above selection process, AnyLogic is decided to be the highest priority for the simulation tool used in this study, followed by FlexSim HC and MedModel.

## 4. SUMMARY

This paper looked at the basics of modelling of ward layouts for simulation purposes and particularly for comparing the productivity of the nursing staff in different layouts. It presented a study of different hospital layout systems used in the last 150 years. As a result of this study, a list of different architectural approaches towards ward design was presented. It was also discussed that most of the main ward layouts of the present can be classified under one of the 5 layout categories (Corridor, Duplex, Racetrack, Cluster and Radial). After deciding on different layout systems, each of these systems needs to be simplified in form of a hypothetical medical unit (ward), including its internal circulation needs as well as its links with other departments in the hospital. This simplified ward will represent the access and circulation qualities of its system in comparison to other types.

To enable these simplified wards to be analysed, they should be modelled based on the design standards and then analysed through one of the available simulation tools to evaluate the level of access and circulation efficiency in each model. A list of some of such simulation tools was presented and some of the most common ones were discussed in detail. Finally the simulation tools most appropriate for the nature of such studies were selected.

As a result, all basics for a comparative simulation study have been established. Using these basics (ward layout categories and their simplified models as well as suitable simulation tools), a variety of different analytical and empirical studies are made possible. One of these potential studies is comparison between the productivity levels of the staff in these different layout types using selected simulation tools. The results of this study will be included in future publications.

## 5. REFERENCES

Alalouch C., P. Aspinall, and H. Smith, 2009, "On locational preferences for privacy in hospital wards", *Journal Facilities*, 27(3/4), p. 88-106

Autodesk, 2010-2, Building Information Modeling, retrieved from the webpage http://www.autodesk.co.uk/adsk/servlet/index?siteID=452932&id=10197177 , accessed 06.04.2010.

Barefoot P., 1992, "The times: Psychiatric wards in DGHs? An architect's comments", *Psychiatric Bulletin*, 16, p. 99-100

Burpee H., 2008, "History of healthcare architecture", *Integrated Design Lab Puget Sound*, UK, Available at: http://www.mahlum.com/pdf/HistoryofHealthcareArchBurpee.pdf

Catrambone C., M.E. Johnson, L.C. Mion, and A.F. Minnick, 2009, “The Design of Adult Acute Care Units in U.S. Hospitals”, *Journal of Nursing Scholarship*, 41(1), p. 79 – 86

Choudhary R., S. Bafna, Y. Heo, A. Hendrich and M. Chow, 2009, “A predictive model for computing the influence of space layouts on nurses' movement in hospital units”, *Journal of Building Performance Simulation*

DH, 2007, Activity DataBase V.20.3; *Getting started guide*, Department of Health

Dilani A., 2010, Presentation, *Patient Environments by Design Programme*, London, UK

Dowdeswell B., J. Erskine, and M. Heasman, 2004, “Hospital ward configuration-Determinates influencing single room provision”, *A report for NHS Estate*, England, European Health Property Network

Dursun P., 2007, “Space Syntax in architectural design”, *6th International Space Syntax symposium*, Istanbul, Turkey

Eldabi, T. and T. Young, 2007, “Towards a framework for healthcare simulation”, *Proceedings of the 39th conference on Winter simulation*, IEEE Press Piscataway, NJ, USA

Gesler, W., M. Bell, S. Curtis, P. Hubbard and S. Francis, 2004, “Therapy by design: Evaluating the UK hospital building program”, *Health and Place*, 10(2), p.117-128.

Gibson, D., C. Aldrich and M. Prensky, 2007, “Games and simulations in online learning: research and development frameworks”, *Information Science Publishing*, Hershey, USA

HBN 4, 1997, Health Building Note 04-01: In-Patient Care : Adult In-Patient Facilities, Department of Health, London

HBN 4 Volume 2, 1998, Health Building Note 04-01: In-Patient Care : Critical Care, Department of Health, London

James, W. P. and W. Tatton-Brown, 1986, “Hospitals: Design and development”, *Architectural Press*, London

Kühn, D. C., 2000, “From intelligent hardware to networked infrastructure”, *Austrian Architect Studios*, Graz

MAPS (medical architecture planning system), 2010, “Principals of Hospital Planning”, Available at: http://www.maps-jo.com/pdf/Hospita_Planning_Design.pdf

Page, A. and A. E. K. Page, 2004, “Keeping patients safe: Transforming the work environment of nurses”, *National Academy Press*.

Gesler, W., M. Bell, S. Curtis, P. Hubbard, and S. Francis, ,2004, “Therapy by design: Evaluating the UK hospital building program”, *Health and Place*, 10 (2), p.117-128.

Pattison HM., C.E. Robertson, 1996, “The effect of ward design on the well-being of post-operative patients”, *Journal of Advanced Nursing*, 23(4).

Plan & Project Partners, 2005, “The European health property network- Design impact study”, Available at: http://www.bouwcollege.nl/Pdf/CBZ%20Website/English/Full%20Reports/DesignImpacStudyReport.pdf

Rivett, G., 2008, “National Health Service History”, http://www.nhshistory.net, Accessed 12.6.2010.

Rossetti, M. D., R.R. Hill, B. Johansson, A. Dunkin and RG. Ingalls, 2009, ”Introduction to Simio”, *Proceedings of the 2009 Winter Simulation Conference.*

Shepley M., and K. Davies, 2003, “Nursing unit configuration and its relationship to noise and nurse walking behaviour: An AIDS/HIV unit case study”, *AIA Academy Journal.*

Shepley M., 2002, “Predesign and postoccupancy analysis of staff behaiviorina Neonatal Intensive Care Unit”, *CHILDREN’S HEALTH CARE*, 31(3), p. 237–253.

Smith H.L., 1966, *It started with Florence Nightingale 100 years later another tradition is emerging*, UK

Sturdavant M., 1960, “Comparisons of intensive nursing service in a circular and a rectangular unit”, *Rochester Methodist Hospital*, Rochester, Minn.

Trites, D. K., F.D. Galbraith Jr., M. Sturdavant and J.F. Leckwart, 1970, “Influence of nursing-unit design on the activities and subjective feelings of nursing personnel”, *Environment and Behavior*, p. 303-334.